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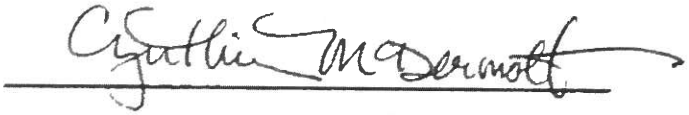
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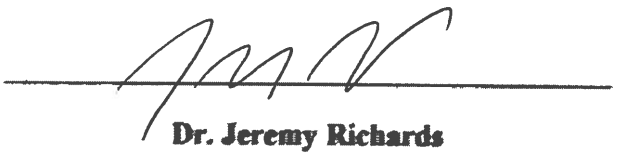
This Thesis, Assessing the effectiveness of Mechanistic Concept Mapping in Case-Based Collaborative Learning, presented by Krisztina Fischer, and Submitted to the Faculty of The Harvard Medical School in Partial Fulfillment of the Requirements for the Master of Medical Sciences in Medical Education has been read and approved by:



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Date: April 24, 2017

ASSESSING THE EFFECTIVENESS OF MECHANISTIC CONCEPT MAPPING IN CASE-BASED COLLABORATIVE LEARNING

KRISZTINA FISCHER, MD, PHD

A Thesis Submitted to the Faculty of

The Harvard Medical School

in Partial Fulfillment of the Requirements

for the Degree of Master of Medical Sciences in Medical Education

Harvard University

Boston, Massachusetts.

May, 2017

Thesis Mentor: Dr. Richard M. Schwartzstein Dr. Krisztina Fischer

Assessing the effectiveness of Mechanistic Concept Mapping in Case-Based Collaborative Learning

Abstract

Mechanistic Concept Mapping (MCM) is a visual method of representing linkages between concepts in order to facilitate deeper understanding of physiological and pathophysiological principles while solving clinical problems. Case-based collaborative learning (CBCL) is a medium-size group approach that combines elements from team-based, problem-based and case-based learning. This study evaluates the effectiveness of MCM in CBCL at Harvard Medical School.

First year medical and dental students (n=170) were assigned into one of four learning societies. One society (n=43) was randomly selected for the "MCM" group; the students in the other three societies (n=127) were in the "Control" group. Outcomes for the "MCM" and the "Control" group were compared using student responses to pre-, post-course surveys and exam scores. A qualitative self-assessment focused on students' perception on their learning was collected mid-course and examined using category construction and inductive approach to analysis.

Overall, "MCM" students' perceptions of their reasoning skills and teamwork was significantly ($p<0.05$) better than their "Control" counterparts. A trend ($p=0.08$) was noted in "MCM" students' higher perceptions on their tolerance of ambiguity when compared

pre- and post-course responses. The course final exam scores for “MCM” and “Control” groups were not significantly different. However, students’ scores on the first quiz in the “MCM” group tended to be higher than the “Control” group ($p=0.09$). Qualitative data analysis indicates that students in the “MCM” group routinely overcame team learning obstacles through strategies aimed at prioritizing collaborative inductive reasoning.

MCM is an easily applicable learning tool that can promote the students’ perceptions of critical thinking skills and teamwork in collaborative learning.

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1. CHAPTER 1: BACKGROUND

There is a continuous and exponential growth in medical knowledge, which makes it impossible to teach and for medical students to learn all the information that they need to know throughout their career as medical doctors (Hunt 1997, Laine 1999, Veronese 2013). Furthermore, much of what they learn in school will be revised and expanded in the years to come. Finally, with the rapid progress of technology, access to information has become extremely fast and inexpensive. Therefore, new pedagogical methods are needed to prepare students for life-long learning and critical thinking as individuals and as members of teams in the biomedical arena (Epstein 2004). Today's medical students may learn as much from their colleagues as from their teachers in medical school; hence, there is a growing focus on collaborative or team-based learning in the medical school curriculum (Dolmans 2015).

In the *Pathways* curriculum at Harvard Medical School (HMS), team-based learning, in the context of Case-Based Collaborative Learning (CBCL), is an integral part of the first year curriculum (Krupat 2016). CBCL focuses on student discussions and aims to promote team learning via high level of student engagement. Another important feature of CBCL is that the students' readiness assessment is accomplished in advance of class, via short essay type or multiple-choice questions based on the learning materials. In class the faculty present a case with a set of open-ended case-based questions. Then students in small groups (four students in each group) discuss the question until they reach consensus within their group. The responses of each small group are subsequently shared and discussed by the entire class, where the faculty serves as the facilitator.

For effective collaborative learning to succeed, shared reasoning among the students is critically important. The following hurdles have to be overcome in collaborative learning in order to be successful: *(1)* superficial discussions without participants being able to articulate their reasoning systematically, *(2)* limited interactions between students – insufficient teamwork *(3)* fear of uncertainty or, in other words, fear of making mistakes, while addressing the problem (Barron 2003, De Leng 2015, Nevalainen 2012). The ability to tolerate uncertainty is valuable not only in medical school but also in the medical profession in general (Simpkin 2016). To successfully practice medicine, physicians have to learn how to approach difficult and complex clinical scenarios and must accept that uncertainty and initial confusion are intrinsic parts of the medical practice (Ghosh 2004, Nevalainen 2010, Luther 2011, Simpkin 2016). As a team students can learn how to use each other's knowledge and expertise to solve the problem together. At the same time effective collaborative work can affect the team and the individual students within the team as they address what is known and unknown in their deliberations. In other words not only can the students solve the problems but also the problems can "solve" the students by helping them to use analytic reasoning and build greater tolerance for ambiguity.

One way to help the students to develop effective collaborative learning skills is the use of concept maps, which are graphical tools for organizing knowledge (Novak 1984). There are different types of concept mapping, which all have unique benefits and limitations in the student's learning (Daley 2010, Guerrero 2001, McGaghie 2004, Torre 2013, Veronesse 2013, Torre 2016, Ruiz-Primo 1996, McClure 1999, West 2002, McGaghie 2000, Ruiz-Primo 2001, McGaghie 2004). The "Mechanistic Concept Map" (MCM) is a diagram that is created individually or collaboratively by a team, whose objective is to analyze a problem step-by-step starting from the main clinical sign or symptom in the case followed by an analysis that makes

explicit the underlying mechanisms of the case findings, and ultimately leading to potential hypotheses or differential diagnosis (Guerro 2001, Rosen 2014). MCMs are helpful in linking prior knowledge with newly acquired information and/or concepts (Daley 2010). They also promote critical thinking by helping the students to think about the problems holistically (Rendas 2006). Despite the advantages of using MCM in individual learning, there is very little known about their benefits in collaborative learning.

This thesis reports the results of a study, which compared students who were exposed to and used MCM as a learning tool versus students who were not exposed to MCM as the teacher's approach to explain the course concepts. The impact of MCM was assessed using three different outcomes: student ratings, exam scores and qualitative data of students' responses to open-ended questions. We hypothesized that MCM would assist in promoting: (1) the use of mechanistic or analytic reasoning (based on students' survey rating); (2) teamwork (based on students' survey rating); (3) tolerance of ambiguity (based on students' survey rating); (4) students' academic performance (based on exam scores). We also sought to understand how MCM assists the teams in their collaborative learning (based on students' responses on open-ended questions).

2. CHAPTER 2: METHODS

2.1 Brief introduction

This work was conducted in February-March, 2016 in Homeostasis I, a required eight-week course for first year medical and dental students at Harvard Medical School (HMS). The course focuses on physiological and pathophysiological principles and clinical manifestations of respiratory, cardiovascular and hematology problems. CBCL is the central teaching method in the first year curriculum at HMS. It combines principles of team-based learning, problem-based learning and case-based learning (Krupat 2015). In CBCL students are working on brief case-based problems (mini-cases) as a group of four and as a medium size group of approximately forty students. Before the course began in 2016, one medium size group (n=43 students) was randomly assigned to the experimental condition (where MCM was used by the faculty and the students to answer a question in the mini-case), while the remaining three societies (n=127) were assigned to the control condition (where MCM was not used as a part of the faculty's approach to answer the questions) (Table 1). Students in the "MCM" and "Control" groups participated equally in all other aspects of the course and received no special instruction other than what was required as part of the course. The protocol was deemed exempt by the HMS institutional review board.

Table 1. Study group assignment in Homeostasis 1 at HMS. One Society was randomly selected for the "MCM" group and the remaining three Societies were assigned to the "Control" group.

Study Group	Number of students
"MCM" group	43
"Control" group	127

2.2 Course material and readiness assessment

Course material was presented to students in preparatory readings, brief concept videos and one-hour long, large group lectures (entire class) four times per week. Students were asked to study the material and complete an online readiness assessment exercise each evening, which included five challenging questions on the topics covered, but not specifically focused on the next day "Mini-case sessions".

2.3 Mini-case sessions

A "Mini-case discussion" was about 90 minutes long, and there were often two sessions per day, four times a week. The content is presented as three questions on a mini-case vignette, for which the answers require students to apply deep understanding of conceptual and factual knowledge in a variety of clinical contexts.

2.4 Faculty description

Two highly experienced faculty members led each "Mini-case session". Prior to the course all instructors participated in a 90 minutes faculty development session, during which the learning objectives were discussed. Faculty members in the "MCM" group had extensive experience with using MCM in physiology and pathophysiology teaching.

2.5 The "MCM" group

One of the session leaders (R.M.S) introduced MCM to the students in the "MCM" group (n=43) on the first week of the course. During the rest of the course, students in the "MCM" group collaboratively created MCM as part of their group discussion in response to the mini-case

questions. The individual or collaborative use of MCM in the students' small group discussions was not required, but strongly encouraged by the faculty. During the medium group "Mini-case discussions" the session leader often organized the information in the mini-case in an MCM, while highlighting the linkages of the data (from the mini-case) and the relevant concepts (from the learning material). An example mini-case vignette and the in-class MCM can be seen in Figure 1.

Pulmonary embolism Mini-Case summary:

Ayse Katenay is a healthy 29 year old woman. Ms. Katenay is traveling from California to Boston on a seven hour plane flight where she is presenting at a conference. Two weeks prior to the trip, she suffered a rock-climbing accident and tibial fracture. She is in a long cast immobilizing her knee. For the last few days prior to the trip, her leg has been more swollen and uncomfortable. She takes oral contraceptives but no other medications. She does not smoke. During the descent, Ayse has the abrupt onset of severe dyspnea and distress. She is having trouble talking and looks like she might pass out. Her HR is 138/min but hard to feel. Her carotid pulse is barely palpable. After arriving at Logan Airport Ayse is brought to the ED by ambulance. A large bore IV is started and she receives a liter of normal saline before reaching the ED. Focused physical exam: She is in marked respiratory distress. Vital Signs: RR 26, BP 92/64, HR 110, SaO2 97% on supplemental oxygen. Chest: few crackles at right base. Heart: neck veins are elevated at 12 cm, tachycardia, normal S1, S2 is split with a loud P2. Extremities: right leg is normal, left leg is in long cast, visible part of the left foot appears swollen.

Question 1. How can you summarize what happened with Ms. Katenav?

Mechanistic Concept Map created by the session leader:

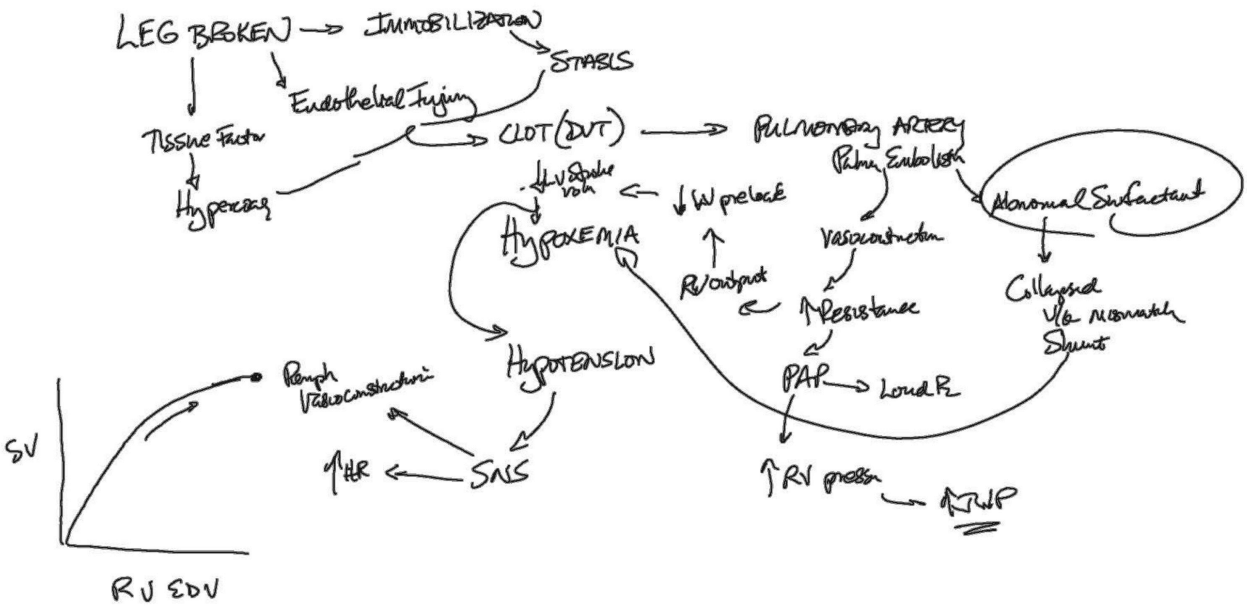


Figure 1. Sample mini-case summary on pulmonary embolism is shown (top) with an example MCM, which was created by the session leader as part of the large group mini-case discussion, in part of the Homeostasis 1 course at HMS.

2.6 The "Control" group

Students in the remaining groups (n=127) verbally discussed the problems, which were complemented by drawing relevant diagrams from the learning material such as a flow-volume loop or a Starling curve in physiologic and pathophysiologic conditions.

2.7 Study sample

Surveys (quantitative assessment): Two surveys were electronically sent out to students: (1) at the beginning of the course (pre-course) and (2) at the end of the course (post-course). All responses were used in the quantitative analysis.

Open-ended questionnaire (qualitative assessment): Nearly all students in the "MCM" group submitted responses to a mid-course open-ended questionnaire. The entire dataset was used in the qualitative analysis. The goal of the entire dataset analysis was to systematically represent a variety of perspectives on the topic under study.

2.8 Outcome measures

Three complementary outcome measures were collected: (1) student ratings of their reasoning skills, teamwork and tolerance of ambiguity as an indicator of *subjective experience*, (2) quiz and final exam scores as an indicator of *individual learning* and (3) student reflections on their collaborative learning as an indicator of *mechanism* by which students benefited from the use of MCM as a group and as an individual (Table 2).

Table 2. Outcome measures that were collected in this study.

Outcome measure	Indicator of
Student ratings	Experience in Reasoning skills
	Experience in Teamwork
	Experience in Tolerance of Ambiguity
Quiz and Final Exam Scores	Individual learning
Students' Reflections	Collaborative process

2.8.1 Student ratings

Students' perceptions were assessed using a series of ratings on a pre-, and a post-course survey hosted at Qualtrics (Provo, UT, USA). E-mailed invitations with a link to the survey were sent to the students in the "MCM" and the "Control" groups on the first day of the course (pre-course survey) and on the last day of the course (post-course survey). The pre-course survey items were written to assess background information such as experience with MCM and self-assessment along two dimensions: (1) tolerance of ambiguity [26 items such as "Ambiguity stops me from having a firm opinion", "It frustrates me not having a firm opinion", Being uncertain means I lack confidence", "A good task is one where what is to be done and how it is to be done are always clear", alpha=0.85] (Budner 1962, Furnham 1994, Furnham 2013) and (2) teamwork [20 items such as "Several members of a team are the main contributors to the success of a team", Each member of a team contributes substantially to the success of a team', "My work in a team is usually integrated into the outcome", alpha=0.83] (O'Neil 1999). All items were answered using the same five-point Likert scale (from strongly agree=1 to strongly disagree = 5). The post-course survey items assessed subjective experience in three dimensions (1) reasoning skills [simple rating scale between 1-10, 1 = no change and 10= much improvement in response to the course], (2) teamwork [simple rating scale between 1-10, 1 = poor and 10 = outstanding] and (3) tolerance of ambiguity [10 items of the pre-course domain, alpha=0.76, five-point Likert scale from 1 = strongly agree to 5 = strongly disagree]. Both in the pre- and post-course surveys students were asked their level of comfort in making mistakes in small group discussion [five point scale of level of comfort: from "very" to "not comfortable"]. The post-course survey also asked students about their perception of usefulness of learning tools such as their own notes, flashcards, MCM and the readiness assessment quiz in conceptual learning [five point scale of

helpfulness, 1 = least helpful and 5 = most helpful]. The potential burden that using MCM or diagrams could have had on students were measured on a five items Likert scale (example questions were "MCM/drawing diagrams made it more difficult for our group to work on problems, because: …creating MCM/diagrams were too long; or …while creating MCM/diagrams we went off topic. Five items, alpha = 0.82, five-point Likert scale from 1 = strongly agree to 5 = strongly disagree). "MCM" students were asked if they plan to use MCM in future courses.

2.8.2 Quiz and final exam scores

Students' quiz and the final exam scores in the "MCM" and the "Control" groups were compared. The quiz and final exam were based on cases similar to the mini-cases but they presented more detail about the patient than a mini-case. Students had access to the quiz and final exam case one and two days before the exam respectively. The test questions were distributed on the day of the test. The first quiz required the most mechanistic thinking, where students had to explain (and cite supporting evidence from the case) in short paragraphs the physiological and pathophysiological principles underlying the symptoms and physical findings in a pulmonary case. The final exam had two cases and the exam questions required students to integrate the respiratory, cardiology and hematology concepts learned in the course. Students were encouraged to study in groups as they reviewed and analyzed the cases upon which the quiz and exam questions were based.

2.8.3 Student reflections

Qualitative data were collected through a mid-course questionnaire focusing on students' perception of their learning experiences to perform an assessment of the impact of the MCM on

students individual and collaborative reasoning strategies. The questionnaire contained three open-ended questions: (1) How have I studied and has this approach been effective? (2) How have I contributed to the learning of my fellow students? (3) How have I learned best thus far in the course?

2.9 Qualitative data analysis

Analysis aimed at explaining "MCM" students' perception of their individual and collaborative reasoning process using an inductive approach to category construction and interpretation of the data (Glaser 1967, Strauss 1998). Descriptive categories were constructed to characterize approaches to overcoming team learning obstacles. To construct the categories, content related students' collaborative reasoning skills was retrieved from coded data derived from the open-ended responses to questionnaires. Relevant sections of text were identified, copied and grouped according to the type of team learning obstacle represented. These sections of text were then reread to characterize the ways in which students overcome these obstacles to avoid superficial discussions of the mini-case problems. The data were reorganized in terms of characterizations to produce an initial category "set". Each category forming the set was named, defined and illustrated with student response quotes. The set was refined – revised, specified and elaborated – through successive returns to the data in which additional sections of relevant quotes were used. Interpretive analysis used in theoretic social science construct to develop an argument based on the categories.

2.10 Statistical analysis

Categorical variables were compared with the X^2 test. Continuous variables were compared with the Student's t-test. P values <0.05 were considered significant ((SPSS 21 software (SPSS Statistics, IBM Corporation, Armonk, New York, USA)).

3. CHAPTER 3. RESULTS

3.1 Student ratings

The response rates for the pre-course survey was 51% (87/170) and for the post-course survey was 54% (91/170). No significant difference was found between the "MCM" and the "Control" students' attitude towards teamwork (2.5±1.1 vs. 2.5±1.0, respectively; p=0.25; on a scale of 1 (most favorable towards teamwork) to 5 (least favorable towards teamwork)) and in tolerance of ambiguity (3.2±1.1 vs. 3.3±1.0, "MCM" vs. "Control" students respectively; p=0.2; on a scale of 1 (least tolerant) to 5 (most tolerant)) at the beginning of the course. At the end of the course, "MCM" students rated their reasoning skills improvement 24% (Average rating ± SD: 8.3±1.9 vs. 6.7±2.5, p=0.02) higher in response to the course as compared to the students in the "Control" group (Figure 2A). Similarly, "MCM" students rated their teamwork 15% higher (Average rating ± SD 7.8±1.6 vs. 6.8±1.7, p=0.02) as compared to their "Control" counterparts (Figure 2B).

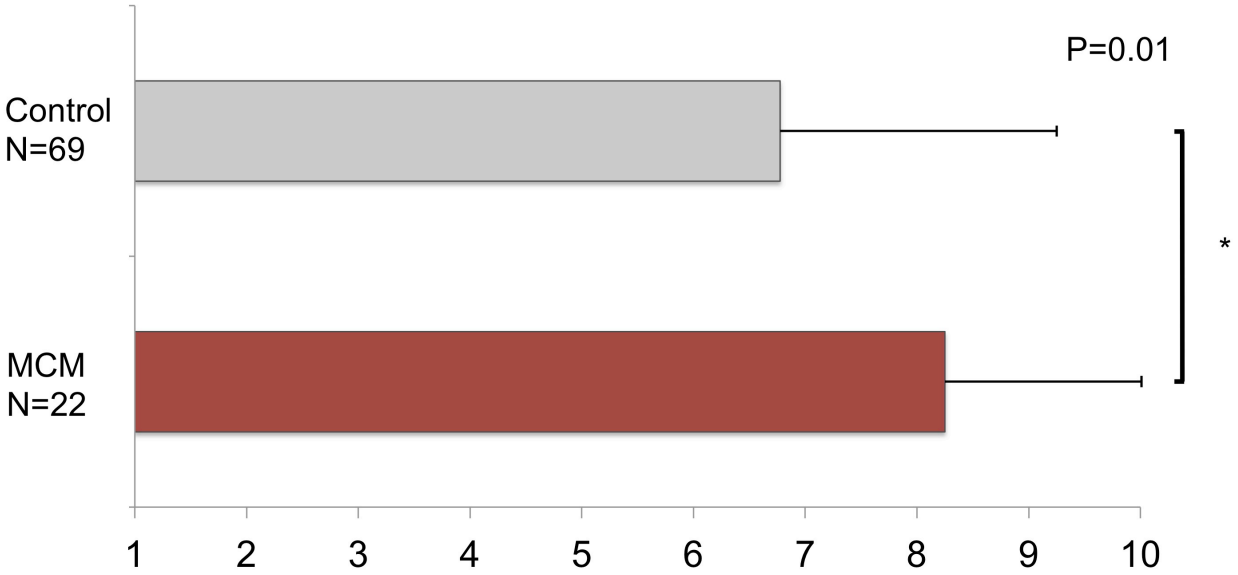


Figure 2A. Reasoning skills rating. In the post-course survey "MCM" students rated their reasoning skills significantly higher than their "Control" counterparts. Average rating ± SD.

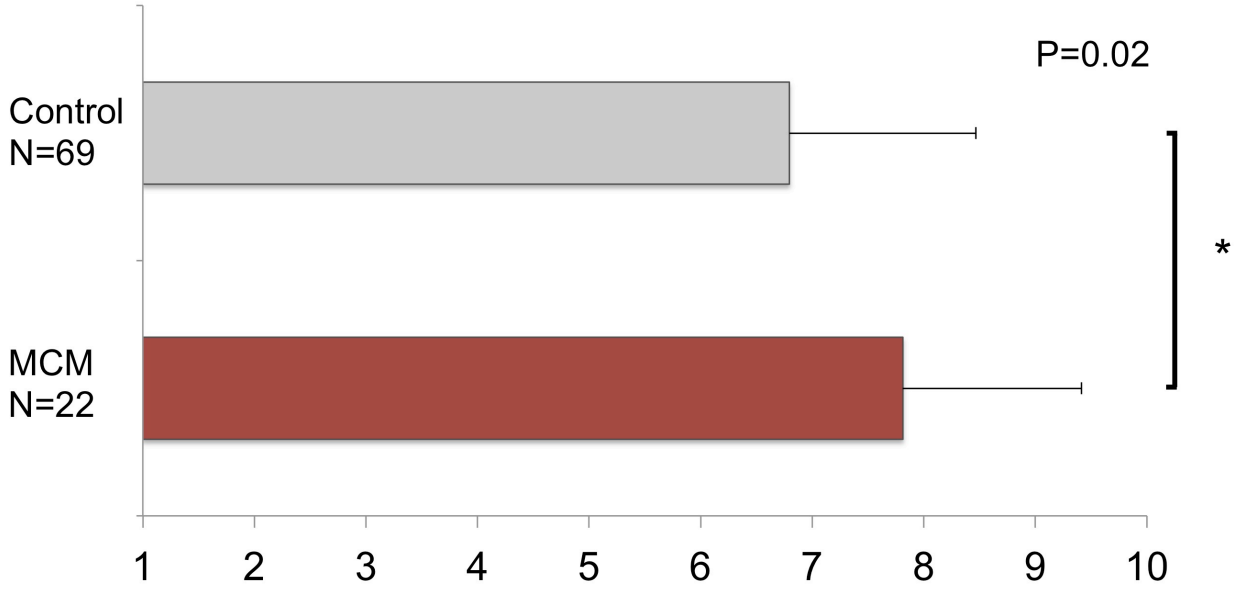


Figure 2B. Teamwork rating. In the post-course survey “MCM” students rated their teamwork significantly higher than their “Control” counterparts. Average rating ± SD.

A trend ($p=0.08$) was noted in "MCM" students' perceptions on their tolerance of ambiguity when pre-, and post-course responses (Average ± SD, 3.2±1.1 vs. 3.4±1.0 respectively, $p=0.08$) were compared (Figure 3A). A similar trend was found in "MCM" students' perceptions on their tolerance of ambiguity when compared to the "Control" group's responses (Average ± SD, 3.4±1.0 vs. 3.2±1.0, $p=0.1$, Figure 3B). Eighty-three percent of the "MCM" students felt very comfortable in making mistakes as compared to 64% of the "Control" students ($p=0.1$, Figure 3C).

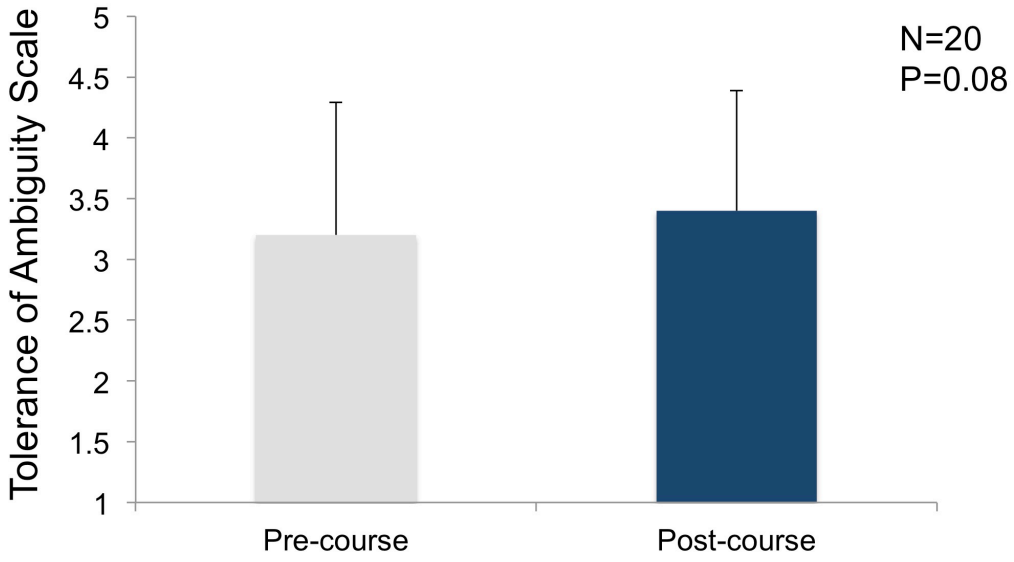


Figure 3A. Tolerance of ambiguity pre- and post-course (Likert scale). MCM" students' Tolerance of Ambiguity Scores slightly increased over the Homeostasis 1 course, indicating a tendency toward better perception for tolerance for ambiguity (Average ± SD, n=20, p=0.08).

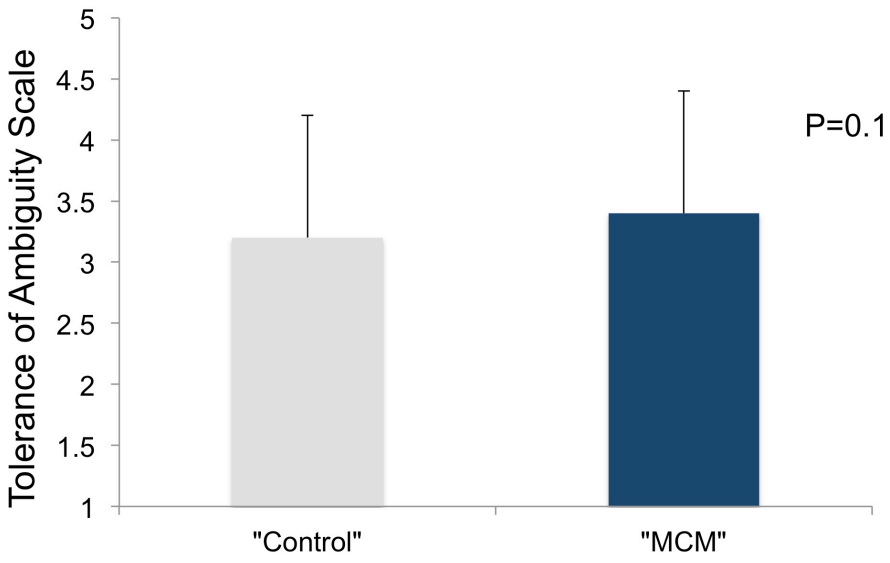


Figure 3B. Tolerance of ambiguity score (Likert scale) in the “MCM” (n=22) and the “Control” (n=69) group at the end of the Homeostasis 1 course. “MCM” students reported slightly higher Tolerance of Ambiguity as compared to their “Control” counterparts, indicating a potential tendency for better perception for tolerance of ambiguity (Average ± SD, p=0.1).

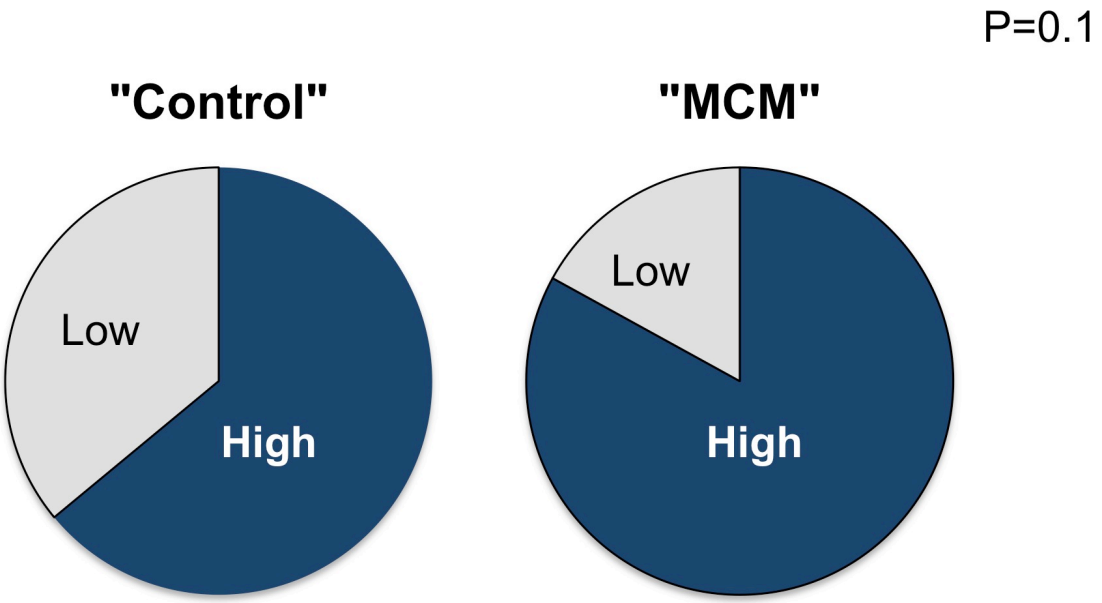


Figure 3C. Level of comfort in making mistakes in the group. In the post-course survey “MCM” students’ (n=20) had a higher level of comfort in making mistakes than their “Control” (n=62) counterparts (p=0.1).

Students found MCM significantly more helpful in their conceptual learning than their own notes and flashcards combined (Average ± SD, 4.2±1.1 vs. 2.7±1.1, $p=0.0009$) on a scale of 1 (least helpful) to 5 (most helpful). Students also reported that MCM was significantly more helpful in their learning as compared to the readiness assessment quiz the night before the "Mini-Case" session (Average ± SD, 4.2±1.1 vs. 2.6±0.9, $p<0.0001$, scale of 1 (least helpful) to 5 (most helpful)) (Figure 4). Ninety-four percent of the MCM students were planning to use MCM in their future courses.

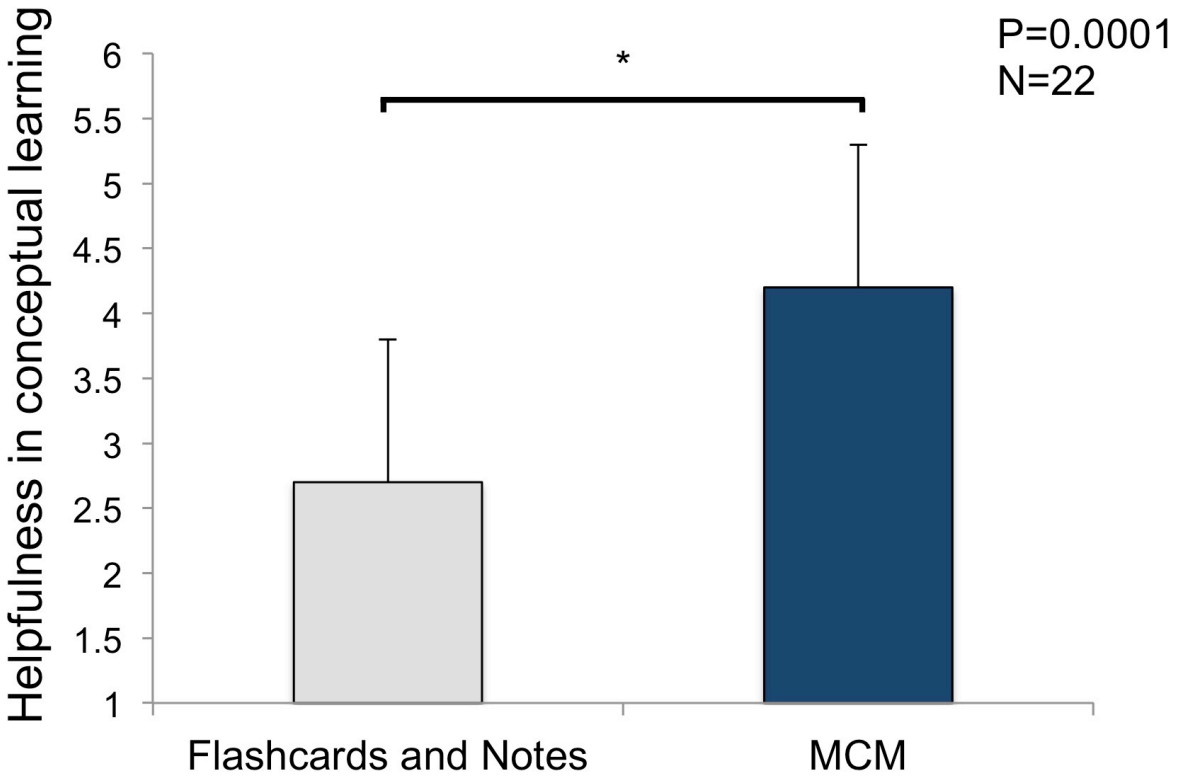


Figure 4A. Learning tool rating in Homeostasis 1. Students rated MCM significantly more helpful in their conceptual learning as compared to their own Flashcards and Notecards combined.

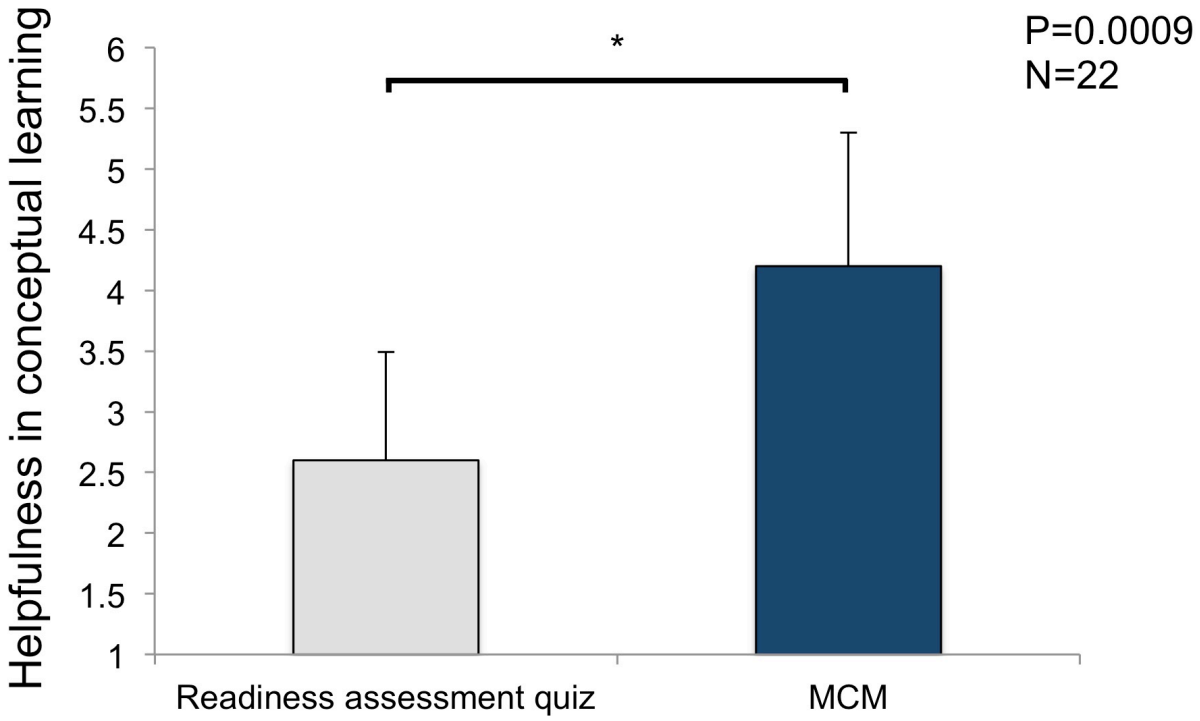


Figure 4B. Learning tool rating in Homeostasis 1. Students rated MCM significantly more helpful in their conceptual learning as compared to the Readiness Assessment Quiz.

3.2 Quiz and final exam scores

The final exam scores for the “MCM” and the “Control” group (148 (82%) vs. 147 (82%), respectively) were not significantly different (p=0.32). However, a tendency was found in the first quiz performance, in which “MCM” students tended to score higher than their “Control” counterparts (39 (65%) versus 37 (61%), respectively; p=0.09) (Figure 5).

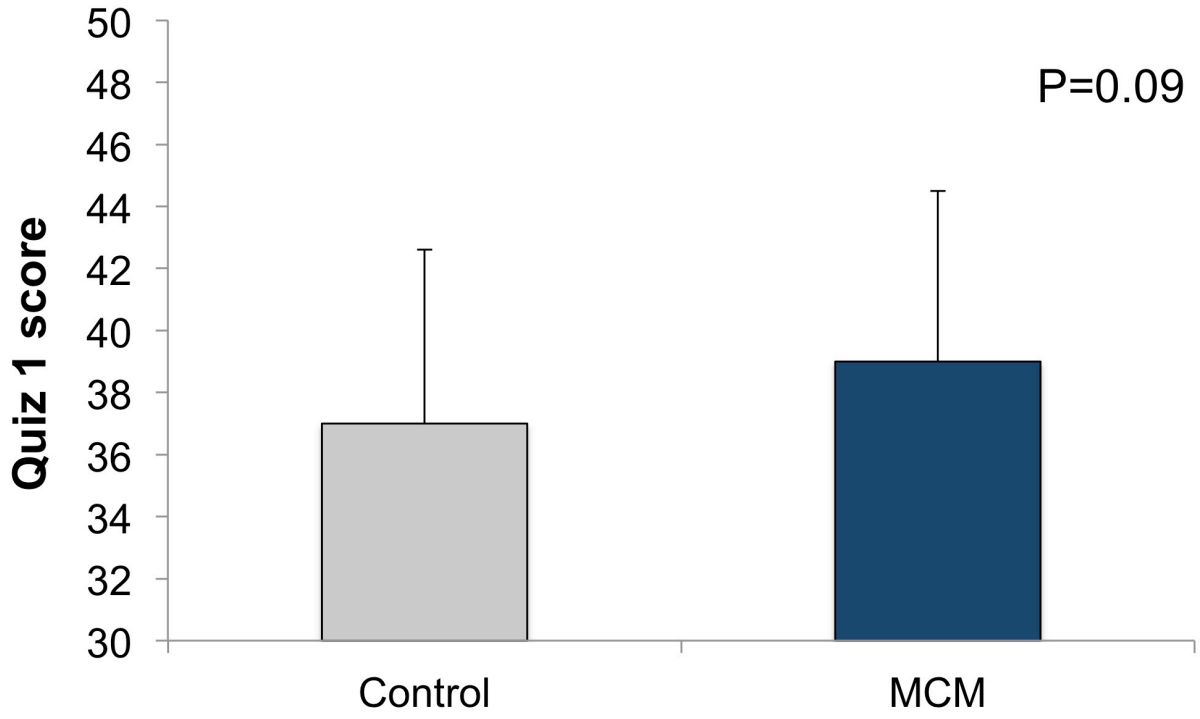


Figure 5. Quiz 1 scores. On the first quiz students' test scores in the "MCM" group (n=43) tended (p=0.09) to be higher than in the "Control" group (n=127).

3.3 Students' reflections

Forty-two students (98% of the "MCM" group) submitted responses to an open-ended qualitative assessment of students' perception on individual and collaborative learning and reasoning process. On the basis of category construction and inductive interpretation of the data, the findings were consistent with: prioritization of collaborative, inductive reasoning in order to overcome team learning difficulties and learn for understanding as an explanation for prioritization and higher perception of collaborative reasoning skills in the "MCM" group.

Qualitative data analysis indicates that students in the "MCM" group routinely overcame team learning obstacles through a number of strategies aimed at prioritizing collaborative inductive reasoning: using (1) "systematic thinking", [quotes: *"S23: "Talking through the concepts aloud makes sure that I don't miss any of the intermediary steps and my classmates can highlight things that I missed and vice versa.";*

"S18: I'm a very visual learner, and I've taken advantage of the personal whiteboards in the learning classroom to draw out concepts/graphs/equations during our mini-case sessions. I think that this has contributed to the learning of my fellow students as we've all come together to tackle our problems utilizing the visual aids.";

S11: "So far I've learned best by breaking the cases down into smaller parts and thinking about it in the form of a concept map."],

(2) "focusing on unclear concepts" [quote: S01: *"The most effective learning method I've utilized in Homeostasis I is concept mapping. I've always been a kinesthetic learner, so taking the time to physically draw a map is incredibly helpful. Not only does it allow me to visualize and*

organize difficult concepts, it allows me to identify my gaps in understanding. I realized that if I cannot comfortably draw an arrow from one point to another, I need to review the material again."] and

(3) "balancing the discussion between students" [quotes: S39: *"If I were able to reach a conclusion after working through the confusing concept, I will share my thought process and sometimes this helped to clarify something for others in my group. If I have not reached a convincing conclusion, the discussion is always helpful."*;

S09: *"Concept mapping has helped me to better describe my own understanding of topics in that if the person I am trying to explain it to still does not understand, I need to think of new ways to get to the point.";*

S09: *Since different members of the group bring different prior knowledge and/or understanding of key concepts to the table, there is usually someone who can explain the topic in question succinctly and clearly;*

S20: *I feel very comfortable sharing my thought process and ideas with the students at my table—really the whole process of discussing and bouncing ideas off of one another. I've tried to encourage quieter people at my table to share their thoughts first, or share part of my thought process, ask people what they think, and if they agree, ask them to share how they would proceed from there"]* (Figure 6).

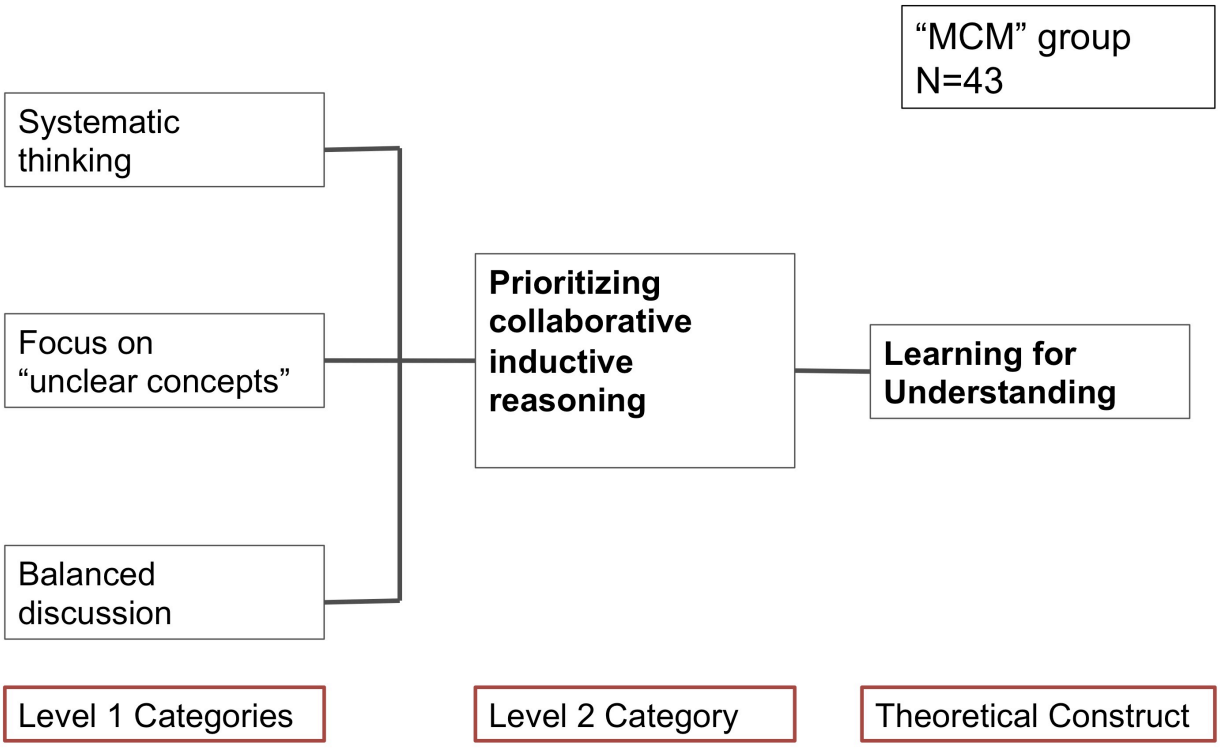


Figure 6. Summary of the qualitative data. Students in the "MCM" group overcome team learning difficulties through strategies (Systematic thinking, Focus on "unclear concepts" and Balanced discussion) that aimed at prioritizing collaborative inductive reasoning in order to learn for understanding as a team and ultimately as an individual.

Prioritizing collaborative inductive reasoning is accomplished through creating visual representations of the students' thinking process (MCM, graph, diagram) and talking through concepts aloud step-by-step during their small group discussions. According to the data, this approach offers a full diagnostic thought process, which takes into account the conditions and concepts learned in the course and helps to fully explore all potential scenarios in which symptoms or signs might arise.

4. CHAPTER 4: DISCUSSION AND PERSPECTIVES

4. 1 Discussion

This work aimed to assess the effectiveness of using MCMs, which are visual representations of the students' collaborative thinking process, in the CBCL environment. Students in the "MCM" group reported a significantly larger shift to more mechanistic reasoning and better teamwork as compared to their "Control" counterparts. The "MCM" students' Tolerance of Ambiguity score showed increased willingness to venture answers and make mistakes over the course when compared to pre-course or "Control" students' rating. Students rated MCM significantly more helpful in their conceptual learning as compared to either their own notes and flashcards or the readiness assessment quiz. While performance on the course final exam was not significantly different in the "MCM" and the "Control" group, "MCM" students' performance on the first quiz tended to be higher as compared to their "Control" counterparts. Since the first quiz required students to use the mechanistic thinking most intensively (the content addressed in the first quiz was more heavily physiologic in nature than subsequent weeks), this trend suggests a possible association between using MCM and higher test performance to be perhaps validated with additional data. Qualitative data indicated that students used collaborative inductive reasoning to promote understanding within the group, thereby advancing their own learning. Ninety-four percent of the students were planning on using MCM as a learning tool in future courses.

These results are important given three factors that worked against the likelihood of finding differences in rating and students' academic performance between the "MCM" and the

"Control" groups. First, students were introduced to the MCM at the same time that they learned the course material, which potentially made it more difficult for them to master the use of MCM. Second, the quizzes and exams were based on common course elements (e.g. reading, concept video, other teaching modalities) and scored based on the same rubric system, yet the students in "MCM" group showed a higher performance tendency. Third, the tolerance of ambiguity scale was adapted from a validated survey instrument (Budner 1962, Furnham 1994, Furnham 2013). Therefore, it was not specific for this study, and the survey items focused on general questions; despite these issues, a tendency was still found in the students' attitude towards tolerance of ambiguity.

Cognitive models for decision-making focus on two systems that underlie our automatic and analytical thinking. System 1 or Type 1 thinking is automatic, intuitive, very fast and effective in pattern recognition. However, it can lead to cognitive bias and serious medical errors when one faces an ambiguous or confounding case (Croskerry 2003a, Croskerry 2003b, Graber 2005, Lambe 2016). System 2 or Type 2 thinking on the other hand is responsible for decision-making that relies on an analytic process (Kahneman 1974, Evans 2013, Croskerry 2014). Although individual invariably incorporate both Type 1 and 2 thinking, awareness of these cognitive models and the benefits associated with more deliberative and analytical approaches to problems, particularly when an ambiguous case is presented can help students (and clinicians) avoid cognitive biases and medical errors (Kahneman 1974, Hayes 2017). The findings presented in this report demonstrate the value of MCM in helping students to consciously use mechanistic thinking and analytic reasoning (Type 2 thinking) when they collaboratively work on a clinical case.

Effective collaborative learning depends on the individuals' willingness to work with new and ambiguous situations, confidence in offering and accepting suggestions to and from team members and the opportunity to work on a task that requires each member's contribution (Edmondson 2001, Hackman 2002, Kost 2015). CBCL aims to use the different knowledge and expertise of each student in the team by asking them to collaboratively form answers to a set of challenging open-ended questions during the mini-case sessions. While what teams as a unit do in CBCL is conversational, creating MCMs during these discussions can serve as a common task that requires everyone on the team to contribute.

4.2 Limitations

Although these results are promising, the findings presented in this thesis have limitations that have to be recognized. We assessed the effectiveness of MCM in a single required course for first-year medical students at a single medical school in a novel learning environment and the sample size was small. Further tests of MCM's effectiveness are needed before any general conclusions about its collaborative learning benefits can be reached.

4.3 Perspectives

It seems that MCM has a great potential in promoting collaborative inductive reasoning, however the results of this work will help us also to better introduce and use MCM in the future. For example, providing guidelines on how to use MCM on a case-based problem is essential to utilize all the benefits that MCM can offer and it was not clear at the beginning how specifically it has to be introduced, described and advised to use to faculty and to students. Judging the "best-practices" (question type, mini-case vignette content, individual vs. co-creation of the MCM, etc.) of using MCM in a small group setting has been a work in progress and we have begun

establishing better guidelines regarding the "best-practices" for the collaborative use of MCM. We are also looking for ways to support the faculty in how to promote MCM in CBCL.

To further understand the impact of using MCM on the collaborative thinking process one could evaluate the teams' discussion, pattern of speech, and types of words and sentences that they repetitively use. During collaborative problem solving, teams have conversational interactions; the discussion pattern can provide a window on the dynamic relationship between team members and their thinking process (Donnellon 1996). Two dimensions of the teams' discussion are especially relevant in collaborative problem solving (1) interdependence and (2) power differentiation (Donnellon 1996, Johnson 2009). Interdependence can be positive or negative; when positive interdependence occurs, students perceive that their individual goal can be only achieved if others in the team achieve their own goals as well (Johnson 2009). Power differentiation can be high or low depending upon how members employ conversational tactics to preserve their status and to influence others (Donnellon 1996). Certain conversational moves, such as "Provocation", "Challenge" and "Posing questions" have been associated with conceptual learning (Hartung 2016). Clear understanding of the effect of successful use of MCM on the collaborative thinking process can be used to shape teams' discussion and create the capacity to increase collaborative inductive reasoning.

4.4 Conclusion

In this study we assessed the impact of MCM in CBCL. We used both quantitative and qualitative measures to evaluate the usefulness of this new collaborative learning tool. We recognize that the conclusions that can be drawn from this single educational study are limited. However, on the basis of these initial results, we suggest that students perceive that MCM is an effective collaborative learning tool, which is consistent with earlier studies on individual learning indicating that MCM promotes inductive reasoning and analytic thinking (Veronese 2013, Daley 2010). Our results suggest that using MCM in collaborative learning benefits emerge in the students' perception of their critical reasoning skills, teamwork and performance.

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