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UNDERSTANDING CHARACTERISTICS OF MULTIDISCIPLINARY COLLABORATION USING CONCEPT MAPS

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ABSTRACT
Integrating disciplinary thinking has become a critical component of higher education in Science, Technology, Engineering, and Mathematics (STEM) disciplines. Within STEM disciplines, students are introduced to a wide range of multidisciplinary projects, courses, and programmes. Multidisciplinary projects require students to collaborate with other students, educators and professionals from diverse academic and professional backgrounds. Working in teams can be challenging for students especially when they are seldom taught how to collaborate with other disciplines. The goal of the study is to understand students' opinions on multidisciplinary collaboration. Students from engineering and design were asked to develop concept maps that illustrate aspects of successful multidisciplinary teamwork. Concept maps were scored by counting concepts, hierarchical levels and cross-links. Content analysis was conducted to qualitatively understand the key concepts and nature of relationship between the concepts. Characteristics of multidisciplinary teamwork were compared across disciplines. Communication, teamwork, conflict resolution, celebrating diversity and finding a common goal were identified as key determinants of successful multidisciplinary teams. The outcomes of the study have several implications for educators and institutions planning to develop or improve multidisciplinary projects, courses or programmes.

Keywords: Concept maps, engineering education, design education

1 INTRODUCTION

In recent years, there is growing demand for student within STEM disciplines to embrace and utilise multidisciplinary approaches to problem solving. The National Science Foundation [1] has identified multidisciplinary problem solving as a critical component to foster innovation. The National Academy of Engineering [2] has emphasised the need to prepare future engineers that succeed in multidisciplinary work environments. As a result, integrating diverse disciplinary perspectives has been a key component of higher education in STEM disciplines.

Students within STEM disciplines are introduced to a wide range of multidisciplinary projects, courses and programmes. Participating in multidisciplinary team projects can be rewarding and challenging at the same time. Working in teams can be challenging for students especially when they are seldom taught how to collaborate with other disciplines. Collaborating with other disciplines requires students to communicate with other individuals, integrate disciplinary perspectives, identify common goals, define workflow, leverage diversity and resolve conflicts in a professional manner. While some aspects of collaboration are covered as part of course content, others are left up to individual students to pursue on their own. If aspects of teamwork are not actively taught and practiced, students can feel frustrated and unproductive in multidisciplinary work environments.

In this paper, we focus on understanding students' perspectives on successful multidisciplinary collaboration. For the purpose of this study, multidisciplinary is defined as bringing together the tools, viewpoints and understandings of two or more disciplines [3] such as engineering and design. Students from engineering and design were asked to develop individual and group concept maps that presented key characteristics of successful multidisciplinary teamwork. Analysis and comparison of concept maps shows remarkable similarities between disciplines. Both engineering and design students identified communication, teamwork, conflict resolution, celebrating diversity and finding common goal as key aspects of successful multidisciplinary teamwork. The findings of the study (students' views) are then compared to current literature and other assessment studies in the field. We conclude by providing guidelines for educators and institutions planning to develop or improve multidisciplinary projects, courses or programmes.

2 LITERATURE REVIEW

2.1 Concept maps

Concept maps are defined as graphical tools for organising and representing knowledge [4]. The roots of concept maps can be traced to semantic memory theory that studies associative networks of knowledge [5]. In a concept map, ideas or concepts are drawn using circles or squares related to a central topic. Concepts are linked to each other using different connectors such as lines or arrows. The lines connecting two concepts are often labeled to express the interdependencies between concepts. Depth of connection between concepts determines the hierarchical level of the map. Cross-links are defined as the number of links between established hierarchies [6]. For example, Figure 1 illustrates hierarchies and cross-link between concepts.

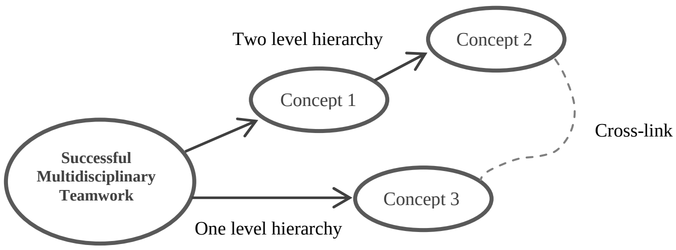

Figure 1. Illustration of hierarchies and cross-link in concept maps

2.2 Multidisciplinary learning assessment

Assessment tools for interdisciplinary or multidisciplinary learning can be broadly classified into two types: classroom-level and curriculum-level. Classroom-level assessment includes an objective measurement of student competencies by evaluating student capstone projects, writing samples, thesis and other interim course deliverables. Several research studies in engineering education [7], [8] have developed rubrics for assessing student work as an indicator of cross-disciplinary competence. Mansilla and Duraisingh [7] outlined three core dimensions of interdisciplinary work: disciplinary grounding, advancement through integration, and critical awareness. Similarly, the study by Wolfe and Haynes [8] outlined four key aspects of interdisciplinary thinking: drawing on disciplinary sources, critical argumentation, multidisciplinary perspectives and interdisciplinary integration. The curriculum-level assessment focuses on subjective self-assessment tools [3] to measure interdisciplinary competence. The wide-ranging survey of undergraduate engineering students showed three scales to measure interdisciplinary competence: interdisciplinary skills, reflective behaviour, and recognising disciplinary perspectives.

2.3 Concept maps in engineering education

Concept maps have been widely used in engineering education to understand student learning and knowledge integration in multidisciplinary settings. Concept maps have been used for both classroom-level and curriculum level assessment in engineering education [5], [9]. Researchers have used concept maps to assess conceptual knowledge [10] and knowledge integration in engineering sub-disciplines [6], [11]. Others have used concept maps as a pedagogical tool to improve students' problem solving performance [12], assess students' ability to synthesise knowledge from multiple sources [13] and to access teachers' practical knowledge [14]. Concept maps have been used as a pre- and post-test to evaluate student learning [15], teaching tool to support student learning [16] and evaluate course effectiveness [17]. The paper shows the importance of using concept mapping as a pedagogical tool for understanding students' views on what makes a successful multidisciplinary team.

3 METHODOLOGY

Thirty mechanical engineering and twenty-eight industrial design students were recruited for the study. Students participating in this study had prior experience of working in multidisciplinary teams. Students were introduced to a short presentation that included how-to instructions and examples of concept maps. This was followed by a warm-up exercise were students were asked to individually create concept maps. The warm-up exercise was helpful for students to practice the task of creating maps. Students were then asked to individually create a concept map for the focus question, "what are the characteristics of successful multidisciplinary teams?" For the purpose of this study, students were provided with the working definition of multidisciplinary teams; teams that bring together the tools, viewpoints and understandings of two or more disciplines [3] such as engineering, design and business. Most students completed the individual concept mapping task in approximately twenty five minutes.

Students were then randomly arranged in groups of four. Each group was then given the same task of creating a concept map for the focus question, "what are the characteristics of successful multidisciplinary teams?" The goal of this activity was to gain a shared understanding of characteristics that contribute to successful multidisciplinary teams. Students reflected on their past collaborative experiences and suggested aspects that were critical to the success of multidisciplinary teams. The group discussions were lively and concept maps showed higher percentage of cross-links. Concept maps were scanned and digitally archived.

Concept maps were analysed using a combination of qualitative and quantitative assessment techniques. The quantitative assessment included [5], [6], and [18] counting three key attributes of each map: concepts, hierarchical levels and cross-links. Counting all concepts (except the central question) represents the breadth of knowledge for each map. A hierarchy shows the levels that extend from the central concept [6]. Two aspects were counted for hierarchy: 1) number of hierarchical levels, and 2) highest hierarchical level achieved. Counting hierarchical level represents the depth of concept maps. Cross-links were defined as the number of links between established hierarchies [6]. Figure 1, shows an illustration of hierarchies and cross-links. According to Turns et al. [5], assessment of concepts, hierarchical levels and cross-links corresponds to the breadth, depth, and connectedness of the knowledge represented on concept maps. Content analysis was conducted to qualitatively understand the key concepts and nature of the relationships between concepts. Researchers did not judge the correctness of concepts or links represented on concept maps.

4 FINDINGS

The following section summarises findings from a qualitative and quantitative assessment of concept maps. The quantitative assessment included counting three key attributes of each map: concepts, hierarchical levels and cross-links. According to Turns et al., [5] assessment of concepts, hierarchical levels and cross-links corresponds to the breadth, depth, and connectedness of the knowledge represented on concept maps. Table 1 summarises the results from quantitative assessment of individual and group concept maps.

In comparison to engineering students, individual maps created by design students showed higher number of concepts, hierarchical level and highest level of hierarchy achieved. Design maps showed more sub-branches for each concept resulting in higher levels of hierarchies; 14.75 (design) compared to 10.80 (engineering). In spite of higher concepts and hierarchical levels, the number of cross-links (represents the connectedness of knowledge) were similar (1.26/1.25) in engineering and design maps.

Analysis of group maps show a significant increase in concepts, hierarchical levels and cross-links for both engineering and design maps. Students enthusiastically participated in the group concept mapping exercise and shared their prior collaborative experiences with each other. Compared to individual maps students took longer to complete group maps. As a result, the group maps show significant increase in concepts, hierarchies and cross-links. The average cross-links for individual maps in engineering increased from 1.26 to 2.6 for groups. Similarly, cross-links for individual design maps increased from 1.25 to 3.2 for groups. Group concept maps showed higher breadth (sub-branches) and connectedness between concepts.

Table 1. Example of a table

Discipline		N	# of Concepts	Number of Hierarchies	Highest level of hierarchy	Highest level achieved	Cross-links
			Mean	Mean	Mean	Count	Mean
Engineering	Individual	30	15.46	10.80	2.4	4	1.26
Design	Individual	28	21.8	14.75	3.2	6	1.25
			Mean	Mean	Mean	Count	Mean
Engineering	Groups	7	20.4	13.2	3	4	2.6
Design	Groups	7	32.2	20.8	4	4	3.2

In the next stage of analysis, content analysis was conducted to qualitatively understand the key determinants of successful multidisciplinary teamwork and the nature of relationship between the determinants (cross-links). Analysis showed remarkable similarities between engineering and design teams. Both groups identified, *communication*, *teamwork*, *conflict resolution*, *celebrating diversity* and *finding a common goal* as the determinants of successful multidisciplinary teams. Organisation was an additional aspect that was seen only in engineering concept maps. Design students did not explicitly mention organisation but included aspects of organisation as a part of communication. The following section briefly summarises key determinants (or aspects) of successful multidisciplinary teamwork with examples.

4.1 Communication

Students highlighted communication as the most important aspect of successful multidisciplinary teamwork. Communication shows the highest number of sub-branches between both engineering and design concept maps. Content analysis of sub-branches shows that communication was arranged on a continuum from logistical requirements to knowledge integration. The logistical aspect of communication included using efficient communication tools such as Google docs, group chats, social media and other aspects such as scheduling, delegation of task, coordination, leadership, and goal setting. The other end of the continuum reflected the abstract interpretation and benefits of communication. This included communication as knowledge integration, developing common jargon, common language, consensus building and developing empathy with other disciplines. Engineering concept maps were more aligned with the knowledge integration aspect of communication, whereas the design maps emphasised the logistical requirements of communication.

A combined analysis of cross-links shows that communication was prominently linked to conflict, teamwork and common goal. Both aspects of communication (logistical and knowledge integration) were considered key to avoid conflict within groups. Communication was also cross-linked with teamwork and finding common goal for teams.

4.2 Teamwork

Concept maps showed teamwork as the next most important aspect of successful multidisciplinary collaboration. Teamwork was interpreted less as a determinant and more as a utopian goal. Teamwork reflected students understanding of an idealistic, productive and high-functioning team. On one end of the continuum, students interpreted teamwork as goal setting. This included knowing your disciplinary process, boundaries, disciplinary contribution and specialisations. At the other end of the continuum, teamwork was interpreted as knowledge sharing, finding a common ground, outlining group expectations, and setting clear goals. Teamwork as a concept was prominently cross-linked to communication and conflict. Maps show a strong role of communication in building successful teams and avoiding conflicts.

4.3 Conflict resolution

Conflict resolution was heavily seen in design concept maps. In comparison, engineering maps show the least sub-branches for conflict. Engineering students chose to focus on communication instead of conflict. Cross-links suggest that good communication will result in less conflict. Conflict was interpreted on a continuum from personal conflict to group conflict. Personal conflict included key aspects such as biases, expectations, motivation to collaborate, excessive ego and appreciation of cross-disciplinary knowledge. This reflected students’ individual struggles and mindset required to successfully collaborate. Group conflict included overcoming problems, setting common goals, sharing disciplinary jargon and professionally resolving differences. Conflict resolution was closely linked to communication, teamwork and setting common goals. Design students felt conflict resolution was important whereas engineering students focused on communication and setting common goals as a way to avoid conflict.

4.4 Celebrating diversity

Both engineering and design concept maps show diversity as a strong determinant of successful teamwork. On one end of the continuum, diversity was sub-divided into learning styles, biases, educational background, disciplinary knowledge, diverse viewpoints and different processes. At the other end of the continuum includes diversity as age, gender, culture, race, domain specific perspectives and forms of knowledge specific to disciplines. Diversity was cross-linked with conflict resolution.

4.5 Finding a common goal

Finding a common goal was considered a prerequisite and a connecting thread to communication, teamwork, conflict resolution and diversity. The cross-links suggest that finding common goal was essential element for all the above mentioned determinants. The goal of communication and conflict resolution was to achieve a common goal acceptable to all team members.

5 CONCLUSION

In recent years, there is a growing emphasis on preparing engineering [1], [2], [3], [6], [7], and design students [19] for multidisciplinary collaboration. Several scholars have reviewed literature [3], conducted classroom-level assessment [7], [8] and curriculum-level survey of multidisciplinary competencies. According to literature [3], collaborating in multidisciplinary teams requires awareness of disciplinarily boundaries, appreciation of disciplinary perspective, appreciation of non-disciplinary perspective, recognition of disciplinary limitations, interdisciplinary evaluation, and the ability to find common ground, reflexivity and integrative skill. Given the demanding list of competencies, working in teams can be a challenging task for students. While some aspects are actively taught in courses, others are left up to students to learn and practice. In this study, we focused on capturing students’ views on multidisciplinary teamwork. Communication, teamwork, conflict resolution, celebrating diversity and finding a common goal were identified as the determinants of successful multidisciplinary teams. These five determinants reported in this study are similar to the aspects identified in literature [3] and other assessment studies [3], [5], [7], [10]. This indicates that current assessment frameworks for multidisciplinary competencies resonate with students’ views. The qualitative analysis of each aspect and continuums suggested in this study should be added to current assessment frameworks.

Educators and institutions planning to develop or improve multidisciplinary projects or courses should incorporate students’ views into their curriculum. Concept mapping, as shown in this study, can be an effective classroom activity to uncover students’ views on collaboration. Concept mapping as an activity will encourage students to share their views and engage in cross-disciplinary discussion. Concept mapping, as an outcome, should be studied as an externalisation of students’ views on the complex nature of multidisciplinary collaboration. We suggest that concept mapping activity should be utilised at different stages of the curriculum and that concept maps be displayed and discussed for shared understanding between team members.

Findings of the study show communication as the most significant aspect of collaboration with highest number of sub-branches and cross-links. At one end, educators should consider the logistical requirements such as scheduling platforms, coordination, team leadership, and goal setting to improve collaboration. At the other end, educators should design exercises that help students understand disciplinary jargon, develop empathy and learn to integrate knowledge. Additionally, results suggest that engineering students emphasised communication and understate conflict resolution. Students should be taught to develop communication and conflict resolution strategies. Multidisciplinary coursework should support diverse learning styles, disciplinary perspectives, and celebrate diverse educational and cultural backgrounds. Finding a common goal was identified as the link that connects communication, teamwork, conflict resolution and diversity. The challenge for educators is to create course materials, learning objectives, activities, deliverables and an environment where students learn to communicate, resolve conflict, celebrate diversity and find common goals. In this study, qualitative analysis of concept maps was limited to content analysis. Future studies should include semi-structured interviews or focus groups with students to specifically understand relationships between concepts (cross-links). In addition, concept mapping activity should be repeated during the course to study changes in students' views on multidisciplinary collaboration.

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