Impacts of interdisciplinary engineering education

IMPACTS OF INTERDISCIPLINARY ENGINEERING EDUCATION: A SYSTEMATIC REVIEW OF THE LITERATURE

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ABSTRACT

With mono-disciplinary courses, students might have difficulties in understanding the role of the content and methods of multiple disciplines in solving complex problems, such as climate change and global health. Considering existing evidence that interdisciplinary learning environments contribute to student progress in e.g., learning, improving skills, a timely review on their impacts can serve as a comprehensive and convincing rationale for the development of these courses in higher engineering education. This systematic literature review aimed to examine peer-reviewed articles reporting on the impacts of interdisciplinary courses on students. The methods used for the review comprised of three phases: 1) search and inclusion of articles, 2) individual study review, and 3) a cross-study comparison. The key search terms identified to locate articles included “interdisciplinary” and “engineering”. The first phase ended with a screening to eliminate articles using the identified exclusion criteria. We completed the second phase that led to a rubric guided by our inclusion criteria (e.g., goals related to student outcomes, courses in engineering education). Part of the rubric included separate sections for student learning outcomes in the domains; knowledge/understanding, skills, and affect. The rubric then was finalized in the third phase following a cross-study comparison. The results can provide a conceptual basis for improving the current state of interdisciplinary courses in higher engineering education. Finally, researchers will be invited to think of new ways to improve the less positive outcomes that were identified, to assess these outcomes and to enhance interdisciplinary courses for online environments.

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1 INTRODUCTION

Over the past two decades, there has been an ongoing shift towards designing interdisciplinary learning environments in higher education contexts. An important characteristic of an interdisciplinary curriculum is its overarching nature which connects methods and content of multiple disciplines [1]. A holistic approach to curriculum facilitates preparing students as individuals who can better contribute to solving societal challenges, such as using resources, climate change, enabling natural security and health systems [2]. It is becoming increasingly important for higher engineering education to expose students to interdisciplinary learning experiences [3].

Multidisciplinarity, interdisciplinarity, and transdisciplinarity are considered as different types of curriculum integration. As seen in Figure 1, there are different curriculum integration approaches [4]. The fragmented approach is similar to the traditional and structured school curriculum with clear disciplinary distinctions; at the lowest end of integration. Multidisciplinary curriculum has a summative nature, whereas a transdisciplinary curriculum connects the disciplines in a way that their unique content becomes indistinguishable [1, 4]. In interdisciplinary courses, there is a loss of the knowledge and methods of the distinct disciplines, while overarching themes or issues are addressed across disciplines [4]. The content and the methods of multiple disciplines are integrated meaningfully around real-world problems [5]. With a similar rationale as that for the review on interdisciplinary engineering education [6], this review embraced both multidisciplinarity and interdisciplinarity due to their frequent interchangeable usage in higher education course contexts.

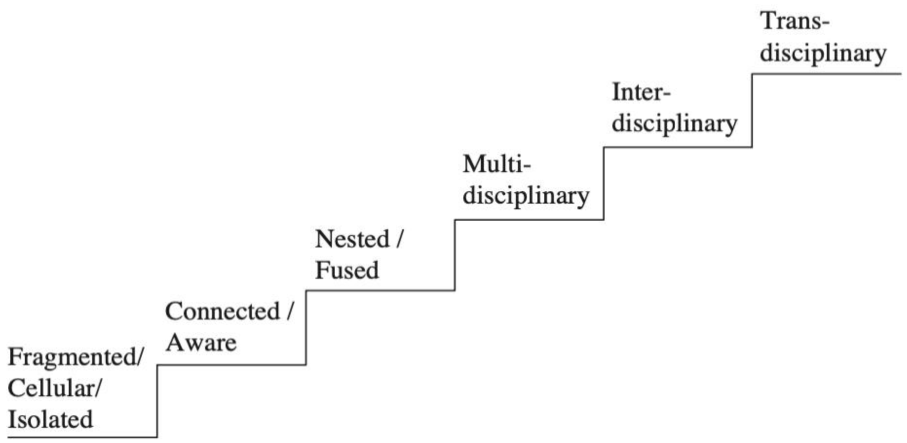

Figure 1. Curriculum integration approaches [4].

Interdisciplinary learning environments are addressed in multiple areas across higher education course contexts, such as health sciences, teacher education programs, social sciences [e.g., 7, 8, 9]. The analytical framework that has been created as a result of a comprehensive review [6], focused on how interdisciplinary engineering education can be best implemented. The review includes three complementary parts: a) vision; the value of and motivation for interdisciplinary education, b) teaching; learning objectives, activities and assessment, and c) support; help provided in terms of teachers, students and the institution. Figure 2 illustrates the details of the three themes of interdisciplinary engineering education.

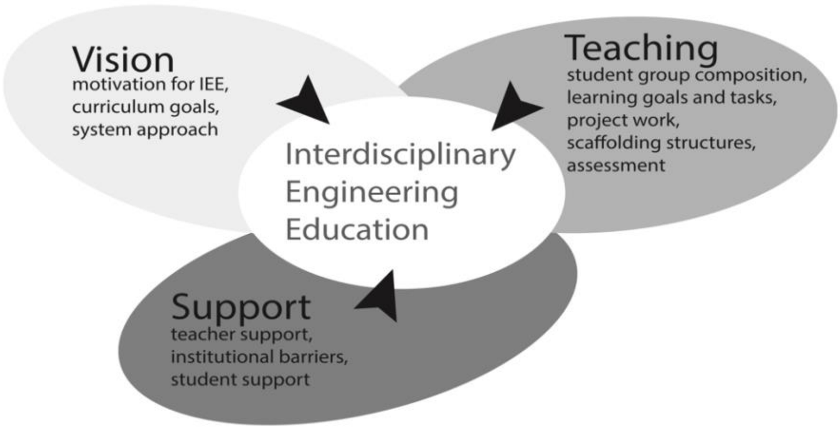

Figure 2. Educational processes of interdisciplinary engineering education [6, p. 511]

Considering the fact that interdisciplinary learning environments contribute to student progress e.g., learning, cognitive skills, competencies to work in multidisciplinary teams [3, 10, 11, 12], a review on student outcomes can serve as a comprehensive and convincing rationale for the development of interdisciplinary courses in higher engineering education. An exploratory study has been conducted on the impacts of interdisciplinary courses on engineering students' competencies [13]. The researchers surveyed a total of more than 4000 engineering students at different time intervals over two years. The findings showed that interdisciplinary coursework had a positive impact on students' leadership skills, interpersonal skills, creativity, and analytical thinking. The authors addressed the need to investigate the influences of similar interdisciplinary learning environments and integrated curriculum activities on engineering students. Integrated curricula have the potential to support engineering students' interdisciplinary thinking and habits of mind [3]. An interdisciplinary course curriculum that incorporated knowledge of neuroscience and engineering was developed [14]. The course content included systems and programming, computation, and neurophysiology. The authors concluded that compared to traditional course structures, the interdisciplinary course they designed for science, arts and engineering students led to an improvement in student learning of the course content.

This systematic review aims to build on the findings of earlier reviews that showed an interest in interdisciplinary engineering education. A literature review previously explored the potential skills and conditions that support interdisciplinary higher education [15]. The list of promising skills and conditions included: a) interdisciplinary thinking e.g., knowledge of disciplines, higher-order cognitive skills, b) student factors; personal characteristics and prior experiences, c) learning environment e.g., curriculum, teacher, assessment and d) learning processes [15]. A second literature review with a focus on vision, teaching and support in interdisciplinary engineering education systematically investigated the articles published until 2017. The authors built a framework helpful for the design of interdisciplinary courses in higher engineering education [6]. Because the schooling system is more commonly structured based on a differentiation of different disciplines, there are concerns about the value and benefits of interdisciplinary approaches [16, 17]. There is a need for further research on the positive impacts of interdisciplinary engineering education, which can eventually be translated into improved interdisciplinary education practices [3]. A timely review can draw attention to interdisciplinary learning environments in higher engineering education by presenting the associated student outcomes. The research question that guided this systematic review was: *What effects of interdisciplinary learning environments on students in higher engineering education have been reported?*

2 METHODOLOGY

This systematic literature review aimed at locating and examining articles published on the interdisciplinary learning contexts in higher engineering education with regards to student outcomes. Adopting a systematic review method helps researchers access, critically examine and synthesize existing research studies [18].

2.1 Phase 1: Search and Selection

The first step in the systematic review included identification of key search terms guided by the goals and the research question of the review. Multiple searches were conducted in the following databases: Web of Science, Ebscho, Proquest, Scopus, and Science Direct. The following key words and their combinations were used during the search trials: “interdisciplinary”, “multidisciplinary” “engineering education”, “students”, “courses”, “teamwork”, “teams”. The review was limited to peer-reviewed articles published between 2000-2021. A total of more than 1000 articles were located as a result of the initial search in the databases. Rayyan (https://www.rayyan.ai) is used for the initial screening and later the full-text examination of the articles. Removal of the duplicates resulted in 751 articles. Next, based on the objectives of the review, five criteria were identified to exclude the following: a) commentaries, book chapters, reviews, reports and conference proceedings, b) articles that do not discuss interdisciplinarity but rather focus on other construct and contexts e.g., distance education, problem-based learning, creativity, c) articles that only address other disciplines/programs (e.g., science, social sciences, health sciences, teacher education) rather than higher engineering education, d) articles on K-12 education and graduate courses, and e) articles not written in English and/or could not be reached full-text. Application of the exclusion criteria significantly decreased the number of articles to 332. As a final step for this phase, 16 articles were added from manual searches in Journal of Engineering Education and European Journal of Engineering Education.

2.2 Phase 2: Individual Study Review

During the second phase; *individual study review,* three inclusion criteria were specified. Identification of the inclusion criteria helped to retain articles eligible for further in-dept examination [18]. Accordingly, to be included in the further steps of this review, the articles had to: a) use a higher education interdisciplinary course, project, (learning) module, activity, or multidisciplinary teamwork as its context which engages engineering students; b) sufficiently present how their context is structured/organized; e.g., course curriculum/materials, elements of multidisciplinary teamwork, conceptual background on interdisciplinarity, etc., and c) report on student outcomes. During the application of the three criteria, the rationales for not including the articles included: solely describing a course or a framework development process and focusing on interdisciplinary research rather than an interdisciplinary learning environment. Using the complementary inclusion criteria, a total of 90 articles were retained.

To facilitate identification of the articles that are specifically linked to the research questions of this review, a quality assessment was also established [18]. The quality assessment was used to decide whether the articles presented sufficient details to be included in further individual analysis. The 90 articles were evaluated using a Quality Assessment Checklist [18, p. 127, 19, p. 742].

Table 1. Quality assessment checklist

	Questions/Indicators	Yes 1	No 0	Unclear 0.5
Objective(s)	Is the research objective clear?			
Method	Is the research context clearly described (e.g., participants, location)?			
	Do the authors state the research methods?			
	Do the authors give an argument for the methods chosen?			
Data	Is data collection clearly described?			
	Are the data analyzed adequately and pricesly?			
	Do the authors report on reliability and validity of the research?			
Conclusion	Are the findings on student outcomes supported by sufficient empirical evidence?			

For each of the indicators on the Quality Assessment Checklist (e.g., is the research objective clear?), the articles will separately be assigned scores; 0: no, 0.5: unclear and 1: yes. 68 articles in total that received more than half of the total score possible were included in the next step.

2.3. Phase 3: Cross Study Comparison

For the final phase of this systematic review; *cross-study comparison*, a rubric is created that includes the categories and the codes for use in the organization and synthesis of the findings [18]. The initial version of this rubric is presented in Table 2. This rubric is based on: a) an initial full-text examination of the 68 articles, b) research questions of this review, and c) the relevant literature. The frequencies and the percentages of the categories and the codes were calculated based on occurrences across the articles [18, 20]. The rubric will be refined for its final version as the authors will complete several more rounds for individual readings of the articles.

Considering trustworthiness, a clear description on how the articles are accessed, eliminated and coded, is provided. The authors are completing the full-text analysis of the articles individually. The rubric is being finalized based on the authors' discussions. An inter-rater reliability score of .80 was calculated as the authors scored the articles during quality assessment [18, 19]. In addition to conducting a reliability check, the meaning of the codes for each researcher will be discussed for the second time after a meaningful period of time (Fraenkel et al., 2012).

3 RESULTS

This rubric containing the frequencies and the percentages for the categories and the codes for 68 articles can be examined in Table 2.

Table 2. Rubric with categories and codes

Categories	Codes (with frequencies and percentages)
Disciplines	Single engineering discipline (n=4, 6%) Multiple engineering disciplines (n=24, 35%) Engineering and other disciplines (n=40, 59%)
Context	Interdisciplinary course (n=38, 56%) Other project-based courses (n=18, 26%) Extra-curricular contexts (n=12, 18%)
Anchors	Problem/challenge (n=51, 75%) Teams that represent multiple disciplines (n=58, 85%) Other (e.g., game, activity, research) (n=12, 18%)

Student outcomes	Beliefs and attitudes (n=42, 42%) Understanding and knowledge (n=24, 24%) Interdisciplinary construct (n=15, 15%) Design products (n=13, 13%) Teamwork skills (n=6, 6%)

The preliminary categories are: disciplines, student outomes, context, and anchor. The first category focuses on the disciplines represented by the students in the interdisciplinary learning environment. Initial examination shows that in some of the articles a single context borrows from the knowledge of multiple engineering disciplines in (e.g., computer engineering, mechanical engineering), whereas majority of the articles report including students from multiple disciplines that included other disciplines in addition to engineering e.g., STEM disciplines, architecture, design, nursing, social sciences, business, computer sciences. The third category; context, reports on the structure of the interdisciplinary learning environment. Results revealed that in majority of the cases, the articles described an interdisciplinary course design. The other interdisciplinary learning envrionments included other project-based courses, trainings, interventions, workshops. In great portion of the articles, multiple disciplines were integrated around a problem or a challenge (75%). Having students with multiple disciplinary backgrounds working tohether in teams is another anchor that is commonly used in interdisciplinary learning envrionments (85%). The final category illustrates the student outcomes in relation to an interdisciplinary learning environment.

4 SUMMARY

This systematic literature review aims to provide an overview of the interdisciplinary learning environments in higher engineering education with regards to student learning outcomes. Systematic reviews are helpful in summarizing and organizing a large body of existing research [18]. This review follows three phases: 1) search and selection, 2) individual study review, and 3) cross-study comparison. For the first phase, searches in multiple databases were conducted with identified keywords. The second phase entailed a further individual examination of the retained articles by using inclusion criteria. The quality check was carried out using a Quality Assesment Checklist with four general indicators: objective, method, data, and conclusion. Following the quality check, the authors are working on the third phase; cross-study comparison. As a result of a preliminary screening, the initial version of the rubric is constructed with frequencies and percentages (see Table 2). With minor modifications, the final version of the rubric will be created after more rounds of individual reading and coding of the articles. Following the creation of the final version of the rubric, the authors will construct a two-dimensional matrix that will show the relations between the identified codes. Based on this matrix, future directions will proposed for developing interdisciplinary learning environments in higher education.

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