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Literature Review of 4Cs Skills in Engineering Education

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ABSTRACT

The twenty-first century (21st century) is the era of information fusion where there is dramatic change in the world of knowledge and technology. In this context, engineering education has been based on the knowledge of science, technology, engineering, and mathematics (STEM) to train the future workforce. This paper focuses on understanding the significance of communication, collaboration, creativity, and critical thinking skills (4Cs skills) in engineering education from previous literature. Analysis displays the specific subs-skills within 4Cs skills needed by engineering students and how to inculcate the skills into students. Communication skills are the most demanded skills in industry while creativity skills are the least emphasized skills in engineering education. There are limited studies to compare whether the skills possessed by engineering students meet the industry demand.

Keywords: 21st Century Skills; STEM; engineering graduate

INTRODUCTION

A quote by Andre De Shield, "slowly is the fastest way to get to where you want to be" is a powerful definition of skill. It describes that while skill acquisition is a lengthy process requiring repeated actions over time, the resulting skill will last a lifetime. In this regard, stability is one of the main benefits of long-term skills acquisition (Hikosaka et al. 2013).

21st century skills are a set of skills needed for a person to function effectively at work, as citizens and in their leisure time. Early learning theories such as behaviorism, cognitivism, and constructivism were introduced in twentieth century where working environment has been very different from fast-changing 21st century workplace that was driven by new knowledge and technology. Therefore, these early learning theories were reviewed by the researchers to produce a better framework of learning for students to enhance their skills.

Connectivism Learning Theory has emerged to understand students' new learning in the 21st century technological advances have allowed learners to use and synthesize information in novel ways and at a faster pace. Siemens (2005) asserted that connectivism is driven by the knowledge that one's judgments are based on quickly changing foundations. Thus, the capability to distinguish between significant and irrelevant information is imperative to process the new information we continuously acquire.

The Connectivism Learning Theory shows that new skills are needed for students to process the vast amount of information in the rapidly changing world of new technology where the sources of information are abundant, and decisions need to be made swiftly and precisely. The skills practiced in the learning environment will prepare the students to become the workforce in 21st century workplaces.

In previous studies by Goldberg (2012) and Triana et al. (2019) the most important skills needed in 21st century workplaces known as 4Cs skills, are critical

thinking and problem solving, creativity and innovation, communication, and collaboration.

To ensure that employees in 21st century workplaces acquire these 4Cs skills, the teaching and learning environment in today's classroom must emphasizes the application of the skills by integrating new methods in learning such as project-based learning (PjBL) that have been shown effective in nurturing the 4Cs skills in student, especially in STEM (Science, Technology, Engineering and Mathematics) (Samsudin et al. 2018; Sinurat et al. 2022).

Engineering education aims to train professionals engineers to take on future endeavors. This is a very challenging objective since it calls for not just a projection of future demands, but also an anticipation of trends in scientific and technological advances. In line with this, core skills required by future engineers should be determined according to the demands and needs of society, academia, employers, and industry (Malheiro et al. 2019).

According to Malheiro et al. (2019), from a worldwide perspective of engineering professional skills, 4Cs skills has been included as required competencies in engineering body in the United States, Europe, the United Kingdom, and Australia.

In 2012, the American Management Association (AMA) conducted a critical skills survey involving corporate associates. The survey focused on determining the core professional competencies required by the 21st century workforce. The result indicated that professionals should possess other skills beyond the basic 3R skills of reading, writing, and arithmetic to be competent in the future workforce. These skills comprise the 4Cs: critical thinking and problem-solving, collaboration and team building, creativity and innovation, and effective communication.

According to AMA, critical thinking and problem-solving skills entail the capacity to decide, address issues, and take appropriate actions. Meanwhile, collaboration and team building comprise one's ability to work well with others, particularly those with different backgrounds and opposing viewpoints. Creativity and innovation refer to one's ability to think outside of the box to execute a task or solve a problem. Lastly, effective communication entails one's capability to analyze and convey ideas in writing and orally (Malheiro et al. (2019).

This paper explores the previous studies on 4Cs skills in engineering education from Scopus and Google Scholar.

COMMUNICATION SKILLS

Gesun & Rizzo (2022) and Ozyurt et al. (2022) believe that communication skills are the most in-demand competency in the engineering field. Employers expect that new engineering graduates will be lack technical proficiency and ready to train them on it. However, it is tough for employers to educate new employees on communication skills such as how to speak and write properly (Mayo & Wheaton, 2022). Employers are looking for new graduates who can listen to instructions, follow directions, and do the job accordingly (Eggleston et al. 2022).

Engineering courses are known to provide fewer assignments that can enhance communication skills such as writing skills and interpersonal skills because engineering programs are usually technically rigorous (Ergai et al. 2022; Renna et al. 2022).

Almeida et al. (2019) has done a comprehensive study in United States on four main industries involving high-tech, automotive, aerospace, and manufacturing. From the study, four major themes were emerged:

1. Theme 1: Commonality of Oral Communication
2. Theme 2: Diverse Audiences, Personalised Messages, and Accurate Platform
3. Theme 3: Explicit, Accurate and Precise Written Communication
4. Theme 4: The Growing Significance of International Communication

Studies have been done to inculcate communication skills in engineering education by replacing traditional laboratory experiment report with new mode of communication such as research posters to encourage students to have more options in presenting their findings and how to deliver it to different types of audiences (Mohalley-Snedeker & Galfond 2022). Lu et al. (2022) investigated a new persuasive communication course design for engineering professionals to prepare senior engineers to perform their jobs requiring a wide spectrum of communication including instructing, inquiring, informing, persuading, motivating, etc.

As engineering is a technical course, technical communication is seen as essential skill for engineering graduates. Engineering students are frequently taught technical communication skills through tasks like lab reports, presentations, or other technical paperwork. In this light, feedback from reviewers or lecturers for their assignments can guide students to improve their technical communication skills (Jenkins & Kecskemety, 2022).

Other learning strategies that can apply to broaden the communication skills of engineering students are interdisciplinary research (Gordon & Kauffman 2022), problem-based learning (PBL) (Rahat et al. 2022),

community service and outreach programs (Moorehouse 2022).

COLLABORATION SKILLS

Collaboration or team-building skills refer to one's capacity to collaborate with others to attain shared objectives. Most workplaces require employees to collaborate in a team with similar background team members or in environments where the members are from different ages, races, religions, academic backgrounds, experiences and so on. Collaboration is necessary in the 21st century workplace where societal problems require a multidisciplinary approach (Kaipa et al. 2022).

Studies have been done to encourage and instill collaboration in engineering students by putting them on cross-disciplinary projects such as with pre-service teachers (Kaipa et al. 2022), business major (Appiah-Kubi 2022) and architecture (Acosta 2022). The first step in building a foundation for implementing multidisciplinary projects in education consists of exposing students to collaborations with people from different fields. In this light, such collaboration could facilitate interactions with diverse stakeholders, customers, and users (Davis & Caldwell 2022). Collaboration between engineering students either between different majors such as civil engineering and systems engineering (Rocha et al. 2022) or across two countries such as the United States and Mexico (Loyo Rosales & Gutiérrez, 2022) also relevant to promote effective communication and collaboration skills, as well as to foster cultural awareness on engineering students.

Izenberg (2022) listed seven specific key skills for effective multidisciplinary teamwork that can be taught within the first year of employment, which are:

1. Maintain consistent, polite communication with those outside of one's discipline;
2. Swiftly becoming familiar with the new industry- or discipline-specific terminology;
3. Rapidly adapt to diverse communication and working styles;
4. Promptly identify and comprehend how one's work contributes to the work of colleagues in other disciplines;
5. Promptly understand and recognize how one's work is supported by the works of his/her interdisciplinary team members;
6. Acknowledge and comfortably admit that one lacks awareness of difficulties encountered by his/her inter-disciplinary teammates; and
7. Show respect for his/her interdisciplinary teammates' choice of career.

CREATIVITY SKILLS

Innovation entails thinking creatively and seeking new opportunities beyond what is already possible (Robinson, 2017), while creativity is a vital skill for engineers especially in solving complex problems that require a creative approach. In this regard, Bruhl et al. (2022) claimed that while engineers discuss innovation willingly, they often feel less at ease when discussing creativity. In this regard, creativity is critical for engineers as they create solutions by utilizing principles from science and mathematics in a creative way to come up with new, useful solutions.

Creativity has been less emphasized in engineering learning outcomes because there is increasing technical knowledge that needs to be covered in engineering courses with limited years of study. Creativity seems to be a broad subject and hard to assess, especially by an academician who is not trained to be creative. Bruhl et al. (2022) argued that instead of divergent thinking — which considers diverse ideas — most engineering programs focus on convergent thinking skills that require deep thinking about a specific idea.

Creativity may come naturally to some individuals like other skills but can also be learned and taught. However, it is important to note that creativity is multi-faceted and requires the integration of skills, qualities, attitudes, and knowledge. Consequently, learners cannot demonstrate creativity and innovativeness optimally if they lack one of these components (Bruhl et al. 2022).

Creative thinking abilities are essential to boost employee productivity in today's IR 4.0 era. In this regard, the engineering curriculum must include all components of STEM and incorporate new approaches that facilitate the development of creative thinking skills (Marsono et al. 2019).

To inculcate creativity in engineering students effectively, project-based learning (Lu et al. 2022) or video essays and podcasts (Caratozzolo et al. 2022) can be used in a learning environment. Han et al. (2022) discovered that both group and individual assignments similarly influence design creativity in engineering students and recommended that educators employ both in their teaching approach. While Donovan et al. (2022) research on integrating art into undergraduate engineering programs shows increasing results in students' perception of their creative skills.

Bruhl et al. (2022) also suggested the creation of communities that encourage and validate creative

development. For example, the tech industry is a community that appreciates creativity skills embodied in their employers and this industry hires a lot of engineering graduates. To support this community, it must build deliberately not by force, and through intrinsic motivation, the people are also capable of tolerating failure, thinking broadly, and embracing any changes to be made.

CRITICAL THINKING SKILLS

Engineer's core work is to create a functional product and the products become more advanced due to rapid change of technology. To thrive in today's 21st century workforce, engineering graduates are required to demonstrate independent and critical thinking skills to tackle intricate and open-ended challenges successfully. There are too many definitions of critical thinking but according to Qamar et al. (2022), critical thinking can be defined as "prudent and rational judgment of external ideas and unprejudiced self-analysis of one's own reasoning (metacognitive and self-reflection skills)". Teaching critical thinking is difficult and there is no specific technique to ensure a student masters these skills, however, it can be nurtured through habitual practice and take time to develop.

Previous research found that critical thinking is effectively taught by modeling the behavior for students to see (Facione, 2000) or by letting the student observe how to solve the complex problem from peers who are good at critical thinking and by giving students difficult tasks that challenge their intellectual capacity (Matthew and Lowe, 2011).

Recent studies proposed that teaching critical thinking can enhance students' self-confidence (Ben Othmane & Jamil, 2022). From previous studies, Qamar et al. (2022) list three approaches to teaching critical thinking; (1) reflective judgment model, (2) concept mapping, and (3) quality practice hypothesis.

In the reflective judgment model, students ask their own questions related to the problem and then generate possible solutions. This is an advanced version of metacognition where students are encouraged to reflect on their own thinking. This exercise of assessing one's own thinking was found reliable to increase critical thinking skills (Ghanat et al. 2022). After a student can develop critical thinking ability in a specific subject, it is important to duplicate the thinking technique on different issues and contexts. Students may need help recognizing which critical thinking skills to apply in their next problems (Qamar et al. 2022).

According to Maryam et al. (2021), concept mapping is a visualization technique used to depict relationships. Serving as a valuable learning tool, it facilitates critical thinking by enabling students to engage in meaningful learning experiences. Implementing this method has proven beneficial for students, leading to improved scores on problem-solving tests that assess knowledge recall, transfer, and application. Van Gelder (2005) introduced a hypothesis that revolves around the idea that critical thinking skills can only be improved through extensive and meaningful practice. To effectively retrieve valuable and relevant critical thinking skills needed in diverse situations, students must possess the capacity to recall and connect previous knowledge in a meaningful manner. Consequently, the acquisition of critical thinking skills is a demanding and time-consuming process (Qamar et al. 2022).

Qamar et al. (2022) also agree that critical thinking needs to be practiced for a long time for someone to apply it in their daily life naturally. Students are required to constantly practice from a young age through their middle and higher education to grasp critical thinking skills. Critical thinking should be progressed with new information and experience since these skills involve connecting previous knowledge to bring out a meaningful solution to a problem.

CONCLUSION

Apart from technical skills, the 4Cs skills (communication, collaboration, creativity, and critical thinking) have become essential soft skills for engineering students to compete in 21st century workplace (Ishak & Sukardi 2020). Studies have been done to find the best approach to encompass these skills in engineering education where most of the curriculum focuses on technical skills and knowledge.

Communication skills seem interrelated with collaboration skills, where students need specific interpersonal skills to perform best in collaborative activities. However, communication skills can be applied in individual assignments such as writing reports and presentations. Meanwhile, collaboration skills need to be aware of other member's or partner's conditions such as respecting different cultures and beliefs, listening and accepting other's opinions, and finding a resolution to an argument.

Like creativity and critical thinking, these skills require cognitive capacity and are closely related to technical knowledge of the subject. However, these skills require students to develop unique or new solutions that correlate with engineering discipline. Creativity and critical thinking skills are challenging for students as well as instructors. These skills need time and perseverance to nurture and are tricky to assess performance.

From the literature, vast numbers of studies have been done to tackle this issue but the skills acquired by students still in question either meet the requirement of the industry. Students who have excellent capabilities during undergraduate education may find difficulties in transferring the skills from the learning environment into the workplace setting. Therefore, further studies can be done to find the gap between the graduates' skills and industry demand.

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