21st century competencies in engineering education: initiation, evolution, current, and now whither to

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ABSTRACT

The fibre of engineering education has evolved from knowledge to competencies. This is a logical consequence of the technologically advanced and multifaceted learning environment where engineers are expected to be technically acute along with a set of essential non-technical competencies. This change is referred to as a 'paradigm shift' in engineering education. Hence, the vision of learning is to immerse a progressive, learner-centric, and competency-based learning environment to face the uncertainties of the 21st century. There are various ways to improve the performance of learners by implementing the available competency frameworks, but the need is to initiate a set of essential competencies according to their nature and purpose that can endure across disciplines. In this paper, the evolution of competencies from the essential to the necessary is reviewed. Finally, the benefits of these competencies in relation to the performance of the engineers are discussed in detail through semi-structured interviews conducted with the engineers. MAXQDA, a qualitative data analysis tool, is used to analyse the data. The findings will help the engineers in grooming their competencies according to the industries.

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1 INTRODUCTION

There is a paradigmatic change in engineering education - a shift from mere technical knowledge to transversal competencies. The learning has to be more inclusive, multi and interdisciplinary, oriented towards the situated social and political scenarios. Its vision is to create a progressive, learner-centric, and competency-based learning environment. Active learners and executioners need these competence and skills to deal with the ill-defined and unthought-of problems of the 21st century (Sangwan et al., 2022). Most learners today are natural investigators, researchers, and information synthesisers as a result of their continued use of digital and mobile technology. These competencies help learners to groom themselves as lifelong learners capable of acclimatising flexibly of changes, and collaborative learning and working environment (Redecker & Punie, 2013). Hence, development of 21st century competencies has to be more inclusive (Neeley, 2021) in accordance with current workplace advancements (Moczek et al., 2015).

Preparing engineers for work, global citizenship, and life in the 21st century is a challenging task. Globalisation, new technology, relocation, international competitiveness, ever-changing markets, and transnational environmental and political challenges influence engineers' capacity to survive and succeed. These talents are referred to as 21st century competencies, higher-order thinking skills, deeper learning outcomes, complex thinking, communication skills, etc. by educators, education ministries and governments, foundations, employers, and researchers. Engineering students overestimate their understanding and acquisition of competencies, sometimes cherishing even an idealised perception. If engineers want to be a part of this phenomenon, they must have a deep understanding of competencies (Wilson & Mukhopadhyaya, 2022). This study focuses on the indispensability of essential competencies for 21st century engineers. The questions addressed are: what are the crucial talents that 21st century engineers must develop and master today; how these may assist learners in navigating the problems; and which competencies will engineers require to face these tumultuous and unpredictable problems?

2 LITERATURE REVIEW

Personalisation, informal learning, communication, teamwork, productivity, and content formation, kernel aspects of the competencies and skills, are critical to the overall concept of 21st century education (Singh et al., 2019; Redecker & Punie, 2013). The rising use of technology is changing how learners learn and create new social norms, and finally leading to lifelong and life wide learning. Furthermore, personal skills (initiative, resilience, personal accountability, risk-taking, and creativity), social skills (communication and collaboration, networking, empathy, and compassion), and learning skills (managing, organising, metacognitive skills, and failing forward - or changing perceptions of and responses to failure) are critical to peak performance at the 21st century workplace (Raj & Sangwan, 2020, Redecker & Punie, 2013).

Over the previous two decades, international organisations and commissions, governments, commercial consortia, and private institutions have developed frameworks to address the challenges of the 21st century. While there is no one-size-fits-all approach to educating young people for the 21st century, there are a number of competencies available (Sangwan, 2021). The International Commission on Education for the Twenty-First Century's Delors Report (1996), at the very onset, established the four visions of learning - knowledge, understanding, life skills, and action skills. Several studies (Sangwan et al., 2022; Devika et al., 2020; Griffin, 2012; Partnership for 21st century Abilities (P21), 2005) have highlighted the main skills required to prosper in the globalised world of the 21st century. Creativity and innovation, critical thinking and problem-solving, communication, collaboration, information literacy, technology usage, career/life skills, and personal/social responsibility are found to be dominant 21st century competencies.

Engineers, working in multidisciplinary teams, coordinate multiple competencies to address complex problems (Passow & Passow, 2017) (environment, sustainability, resources depletion, societal living standard, etc.), which call for social competencies as well (Wilson & Mukhopadhyaya, 2022). Service learning (Muñoz-Alcón et al., 2022), active learning (Hernández-de-Menéndez, Marcela), competency-based learning (Henri et al., 2017), learning factories (Devika, 2021), an outcome based and learner-centred pedagogy, may help the engineers groom themselves at personal as well as the citizenship level. Evidence-based competencies have relook at teamwork as coordination, ethics as responsibility taking, lifelong learning as information collection and skill expansion, etc. to exchange information and plans, apply knowledge and skills, and seek problems and solutions (Passow & Passow, 2017).

3 METHODOLOGY

The research approach is categorised as interpretive research with the goal of gaining a deep understanding of the contextual factors and the interviewees' perceptions about the importance of the competencies in 21st century environment. In this qualitative study, open-ended questions and non-numerical analysis were used. The unit of analysis was the critical incident reported by the participants. A critical incident refers to a work situation. This technique allows the interviewees to express their views in their own terms, helps avoid misunderstandings and can create reliable, comparable qualitative data. We used the Critical Incident Technique (CIT) to derive all critical competencies (Koch, 2009). Interviewees were asked the following subquestions: (1) What were the challenges you faced during the initial period of recruitment? (2) How did you overcome these obstacles and progress? (3) What were the consequences of your actions regarding the concrete work situation? (4) What impact did effective problem-solving have on the work's future progress? A total of 30 responses (freshly graduated engineers in recent two years) were collected for this study. To determine how many people needed to be sampled, the concept of theoretical saturation (Glaser, 1992) was used.

All the interviews were recorded and transcribed using the software MAXQDA to conduct content analysis. Although we asked the interviewees all the sub-questions (e.g., what led to this work situation?) together with the main question about a critical incident (please recall an important work situation), the interviewees often did not describe the incident in chronological order, and instead skipped back and forth from one stage to another. Similar incidents and phenomena were then compared and contrasted with each other, and correspondingly coded where they were found to be similar. With the newly added data, the iterative reflection of the already coded data was carried out. Several iterations were done to narrow down the level of granularity of work situations (the consequences of the analysts' behaviour). Subsequently, we compared existing competency models with initial codes to select a model that fitted the data well. It consists of eight competencies and 30 components of competencies at the finest level of detail, where no competency is subsumed by any other competency. The framework of the competencies contained detailed definitions, including behavioural indicators, which were adapted to the role of the engineers.

4 RESULTS

Based on the perception of the graduated engineers, the study identified eight competencies (see Table 1) which cover eight high-level competency factors. When the participants were asked about the challenges they faced during the initial period of recruitment, they reflected on various problems, including the transition from the learning environment to the execution environment. Working under pressure (dominated by seniors), taking responsibility (afraid of taking the responsibilities of the task due to their newness in the working environment), working by themselves (working on their own without seeking assistance from experienced people), working with people from different backgrounds, being afraid of failure, dealing with superiors, not knowing enough languages, etc. The second interview question referred to the methods (competencies) of overcoming the challenges used in situated work. The definitions of these competencies garnered against the setup of particular work situations, contextual factors (antecedents) are shown in Table 1. The third interview question dealt with the consequences of the actions taken regarding the concrete work situation. The fourth interview question addressed the stages of the implementation of the competencies at various levels, which can help the engineers in managing and solving the problems.

Table 1. 21st century competencies of the engineers

Competencies	Components	Findings
Creativity and innovation	Fluency of ideas	Generate a variety of ideas about a given issue (the number of ideas is important, not their quality, correctness, or creativity)
	Flexibility (variety of ideas)	Be flexible in developing a wide range of thoughts and reactions across several categories to observe things

		from various perspectives. Also think about and transition between different notions at the same time.
	Originality (uniqueness of ideas)	Originality is frequently related with qualities like imagination, persuasiveness, and creativity.
Critical thinking and problem-solving	Critical thinking	Analyse, interpret, infer, explain, observe, reflect, self-regulate, and self-evolve to solve the problem.
	Application skills	Apply domain knowledge and skills, contribute to the assigned role, and accomplish work tasks smoothly.
	Problem finding	Develop critical thinking to necessitate observation to identify and resolve the problems, based on previous experience, to forecast the problems.
	Information collection	Check the data's origins and credibility to see if the findings are based on facts or merely views.
	Reflective thinking	Develop higher-order thinking skills, relate new knowledge to prior understanding, think in an abstract way, develop questioning attitude, identify areas for improvement, and encourage active engagement.
	Decision making	Take work responsibility, demonstrate commitment to appropriate decisions to ensure work ethics, generate and evaluate alternatives before making a decision, and select the option that balances risk and reward.
Communication	Verbal	Communicate verbally in straight forward and appealing ways especially during discussions where the managers/team take appropriate actions.
	Confidence	Be confident during hostilities to solve and understand the problem and communicate with the higher positions people to state the ideas and intentions clearly.
	Concise	Be concise in communication by sticking to the point, keeping the information brief, constructing sentences carefully, and using grammar properly.
	Feedback	Take and give feedback to evaluate the effectiveness of messages by ensuring no miscommunication.
Collaboration	Negotiation	Exercise general, special, and specific coordination to provide reliable psychophysical readiness and suitability for quick, effective, and successful solutions.
	Cross-cultural sensitivity	Accept and respect other cultures and others' cultural identities. Cultural sensitivity counters ethnocentrism, and involves intercultural communication.

	Organisation	To be organised, prioritise and organise tasks meritoriously, share information equally in a team, create a plan for success, ensure proper training, and conduct regular meetings to get suggestions.
	Open-mindedness	Be open- minded and unbiased to listen to others and reduce interpersonal or intra-team conflicts in the team.
Information literacy	Digital/social media management	Have a great understanding of digital marketing and online based digital technologies such as desktop computers to promote products and services.
	Critical media content evaluation	Access, retrieve, understand, evaluate, create, and share information/media content in all formats through media platforms with regards to the materials available for scrutiny in the different forms of media/information.
	ICT attainment	Be critical in applying logical/critical thinking to evaluate the information. Use computer operating systems to produce common digital information and use internet to update the company's social media accounts.
Technology usage	Technical writing	Express difficult information in writing in a clear and understandable manner about products and services.
	Project management	Develop technical initiatives and project management skills to master complicated systems and programmes.
	Productive software applications	Master productivity in general and customised software such as word processing, spreadsheet, and presentation to complete tasks professionally.
Career/life Skills	Self-awareness	Perceive self-strengths and preferences to recognise effective stress management strategies.
	Coping with stress	Be physically and mentally healthy to deal with stressors in the company. Identify what causes stress, how to cope with them, and how to avoid them.
	Coping with emotions	Understand/manage personal emotions in the company to entail greater knowledge of the conditions that trigger negative feelings and investigate the appropriateness of emotional responses to certain situations.
	Healthy interpersonal relationship	Maintain a healthy interpersonal interaction in the team through compassion, empathy, emotional reciprocity, effectual communication, etc. to create and sustain a healthy relationship in the company.
Personal/social responsibility	Environmental responsibility	Work in an ecologically responsible manner. Reduce pollution, increase reliance on sustainable resources, and offset negative environmental impact to maintain corporate social responsibility.

	Ethical responsibility	Ensure ethical responsibility to certify that the organisation operates in a fair and ethical manner. All stakeholders, including leaders, investors, employees, suppliers, and customers, should be treated fairly by organisations.
	Economic responsibility	Take responsibility for all the economic factors related to the environment to give a positive impact, not just maximise profits.

5 DISCUSSION

On an average, important work situations described by the interviewees required two main competencies to identify the problem (communication and collaboration). When freshly graduated engineers joined industry, they faced challenges in terms of adjusting to and understanding the working environment. In such situations, they are expected to learn from an expert (feedback/suggestions) about their performance. This can only be done if the team members are open-minded and willing to share.

The second stage is to solve the problem, where engineers are to use critical thinking and problem solving, creativity and innovation, information literacy, and media literacy (four competencies). Critical thinking and problem-solving abilities allowed them to apply higher-order thinking to new problems through acceptable reasoning and suitable decisions (for non-routine problem solving). Critical thinking requires an understanding of the surroundings and resources to avoid problems; creativity and innovation assist in inventing new ideas/approaches to look at the problem from a different perspective. In the new technological environment, special emphasis is placed on knowing how to best apply technological knowledge during a crisis. Such technology usage strengthens the ability to find and apply appropriate tools resourcefully, ethically, and successfully. Information literacy and technology go hand in hand, where information literacy provides the capacity to obtain, assess, synthesise, and disseminate information from a variety of disciplines.

When it comes to the third stage of the experiences that are learned from both the stages, two competencies (personal/social responsibility and career/life skills) are important. Personal and social responsibility allow us to collaborate with others by identifying and respecting cultural differences while dealing with people from various cultural and social backgrounds. Career/life skills make engineers self-directed and autonomous learners who can embrace change, manage projects, exhibit ownership of their work, lead others, and generate outcomes.

While conducting the interview, an interesting observation comes in terms of competency knowledge. Barriers seem to be that the competencies are either not widely known by the participants or they tend to avoid the effort of understanding and implementing the learned competencies in the workplace, such as career and life skills, critical thinking, and creativity. Additionally, the criticality of having high technical knowledge and information literacy is not sufficient in conducting the

smooth functioning of the work. The interviewees also stated the importance of these skills in getting the job. Individual Competencies assist individuals by (a) summarising the experience and insight of seasoned practitioners; (b) providing a tool that individuals can use for their self-development; and (c) outlining a framework that can be utilised to help select, develop and understand the effectiveness of engineers. Thus, the effectiveness of engineers' jobs often depends upon specific combinations of these competencies.

Engineers should be able to communicate across a wide range of cultures because they work with such a diverse group of people. Collaboration concentrated on the active integration of all the team members into all aspects of the decision-making process. The participants' most common theme was that they needed to improve their communication abilities. They regarded communication essential for successful career advancement. Regular communication, early presentation of concepts, and feedback seeking help in maintaining a healthy and friendly environment at the workplace. However, it was not always sufficient to solely concentrate on creating a friendly environment. In some cases, this even led to unsuccessful project outcomes when teams, for example, wanted to keep doing their work exactly the same way despite possible improvements or when they underestimated the technical complexity of the desired software product. In this situation, the team has to develop innovative ways of working by improving their information literacy and technological knowledge. Blurring the barriers of culture and behaviour leads towards a healthy relationship and a positive outcome of the work. Engineers are required to behave independently, make judgments, and collaborate with peers in real-life situations. As a result, collaboration provides an opportunity to engineers on the periphery to integrate their knowledge and abilities into the core of the engineering community.

6 CONCLUSIONS

The paper elaborates on a 21st century competency model, thus contributing to theory in the critical area of competency evolution. The study sheds light on the specific situations at the workplace for newly recruited engineers. Overall, the paper triggers the need to link competencies with specific situations and stages so that the newly graduated engineers can consciously work on grooming their competencies. Based on the result, it might be possible to connect the identified competency profile with existing standard tests used in HR management. This would enable a better and easy-to-apply recruitment process. It also facilitates better individualised training programmes for engineers. Moreover, this paper shows how other engineering-related job profiles can be analysed and, correspondingly, explored and developed. The main limitation of research refers to the derivation of the model from interviews. However, the participants explained in detail how a specific behaviour had impacted the further advancement of the work.

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