Volume 26, Number 3, 2024

Global Journal of Engineering Education

Associations between components of systems thinking and soft skills among engineering students

Aziz Shekh-Abed† & Nael Barakat‡

Ruppin Academic Center, Emek Hefer, Israel†
University of Texas at Tyler, Tyler, United States of America‡

ABSTRACT: Systems thinking and soft skills are separate yet interconnected concepts that significantly influence an individual's personal and professional achievements. Systems thinking is a cognitive style that focuses on the interactions and relationships within complex systems. Soft skills include a holistic perspective, effective communication, problem-solving abilities, teamwork, flexibility and emotional intelligence. Using a quantitative research method, this study examines the associations between different components of systems thinking and soft skills among engineering students, to provide insights to educators that can help in designing better activities that integrate both skill sets holistically and efficiently. Ninety-two students from the University of Texas at Tyler, USA, were invited to fill out an anonymous Likert-style questionnaire about their self-reported systems thinking and soft skills abilities. The findings reveal moderate and significant correlations between different components of systems thinking and various soft skills, shedding light on the symbiotic relationship between these cognitive and interpersonal competencies. The outcomes of this research have implications for engineering curriculum development, pedagogical strategies and industry expectations.

Keywords: Systems thinking, soft skills, engineering students, problem solving, teamwork

INTRODUCTION

In order to achieve success, an engineering team must possess a diverse set of competencies that encompasses both systems thinking and soft skills. Systems thinking refers to the cognitive ability to adopt a holistic perspective that covers the entirety of a system rather than focusing on isolated components. This approach involves considering the intricate interconnections and interdependencies that exist between the system under examination and its broader external environment [1]. Soft skills refer to the ability to interact effectively and harmoniously with people [2]. Active engagement in auditory perception, verbal communication (both internal and external), cognitive processing (in a discerning manner), and synthesis of information are vital components of all forms of technological endeavours. Studies have been dedicated to the individual development of these two abilities among engineering students, due to their significant relevance in engineering practice [3][4].

The current study investigates the associations between several elements of systems thinking and various talents in soft skills among engineering students. This study offers a theoretical contribution by providing a comprehensive quantitative analysis pertaining to the assessment of systems thinking and soft skills within the context of engineering education. The practical contribution of this endeavour involves facilitating the creation of instructional activities aimed at fostering systems thinking and soft skills among engineering students.

The article first reviews systems thinking and soft skills. Then, the study objective and the methodology are presented. Finally, the main findings are discussed and concluded.

SYSTEMS THINKING

Systems thinking is an analytical approach that facilitates the comprehension of intricate systems through the examination of interconnections among their diverse constituents and an analysis of the manner in which these constituents influence one another to accomplish a shared objective [1]. The process entails the comprehensive examination of the complete system, including its constituent elements, interconnections and methods of feedback, with the aim of devising and enhancing the system as a unified entity. Furthermore, the application of systems thinking guarantees the adoption of a comprehensive viewpoint, encompassing the performance of the entire system, and the inclusion of all pertinent components during the implementation of change. Systems thinking refers to the capacity to articulate and assess the intricacies of dynamic complexity, which arises from the interactions among actors within a system over a period of time. This can be accomplished by textual and visual means [5].

The concept of systems thinking serves as a foundational framework for systems engineering since it establishes the interconnections between the many elements within a system, as well as the relationship between the system and its external environment [6]. Alignment of teams, disciplines, specialties and interest groups is of utmost importance. Systems thinking enables a comprehensive understanding of a system's functioning, without necessitating the disclosure of every minute detail. This approach considers the interconnections and collaborative effects within the system, while also acknowledging non-engineering elements, such as economic, sociological and organisational issues. The ability to assess both technical and social connections and utilise this knowledge to construct and oversee intricate systems poses a significant challenge in contemporary systems engineering practice [7]. In recent years, scholars have conducted extensive research on several aspects related to the capacity for engineering systems thinking. These investigations have focused on individual attributes, abilities, and attitudes, as well as on team characteristics [8-12].

Systems thinking is further distinguished by improved capabilities that boost the effectiveness of the different processes involved in the design of a system. These processes include evaluating system requirements, generating design concepts, conducting functional analysis and optimising the ultimate system [12]. Systems thinking has been found to enhance interpersonal skills, including the ability to contribute effectively to teamwork and demonstrate leadership qualities, as individuals gain a deeper understanding of their role within the broader context [1]. The existing body of literature offers an extensive discussion of numerous endeavours aimed at showcasing the incorporation of systems thinking into the instruction of engineering students across different educational stages, as well as evaluating the effectiveness of these endeavours [13-16]. One of the primary findings of these studies suggests that the acquisition of systems thinking is most effectively achieved through active learning in a collaborative team environment [17].

SOFT SKILLS

Soft skills encompass a wide range of abilities, including interpersonal skills, as well as qualities, such as social responsibility, creativity, ethics and emotional intelligence [2]. Soft skills involve the heightened capacity to successfully communicate and engage with others, the aptitude for critical thinking, and the integration of professionalism within the realm of engineering practice [18-20].

Organisations place significant emphasis on the development of interpersonal skills, such as the ability to establish rapport, as well as communication skills, including the capacity to tailor messages to suit specific audiences. The importance of soft skills in the field of engineering has been emphasised by several institutions, including the National Academy of Engineering and the Accreditation Council for Engineering and Technology, leading to several scholarly contributions that have enhanced the existing body of research on the integration of soft skills within educational curricula [21].

A study conducted by the Monarch Institute found that a significant majority, specifically 85%, of the skills necessary for employability are classified as soft skills, while the remaining 15% are categorised as technical skills. This highlights the need to incorporate the instruction of soft skills into the educational setting. Research indicates that engineers must have the ability to assimilate new information and articulate their opinions effectively, in an independent, critical and proactive manner. In order to fulfil their roles effectively, engineers are required to cultivate intrapersonal and self-management skills that facilitate the regulation of impulsive tendencies, the fulfilment of commitments, the acceptance of accountability and the management of stress. Moreover, empirical studies have demonstrated that engineering students must possess the skills of collaboration, interdisciplinary coordination, and societal understanding in order to effectively innovate and address complex real-world challenges. It is imperative for students to critically assess the environmental, ethical and political ramifications of their actions [22].

According to ten Caten et al, soft skills hold greater significance in the field of engineering than do technical talents, both during their current studies and as future practitioners [23]. A multitude of non-technical competencies exist that enhance the capacity of professionals to assume leadership roles in their professions and effectively adapt to market demands. These characteristics include leadership, innovation, communication, management, ethics, agility, resilience and adaptation. The essential competencies required for managerial and leadership roles after completing university education are cultivated through the study of humanities and social sciences. These competencies include exhibiting enthusiasm and curiosity, embracing existing roles and obligations, while actively pursuing personal growth, acquiring experience through involvement in diverse projects and collaborative teams, comprehending and addressing organisational obstacles, engaging in self-reflection to derive lessons from errors and fostering values that promote trust [24].

RESEARCH OBJECTIVE

The objective of the study was to explore the associations between different components of systems thinking and various soft skills among engineering students, so as to provide educators with information that will assist them in planning more effective activities that combine both skill sets holistically and effectively.

METHODOLOGY

Participants

A total of 92 engineering students from the University of Texas at Tyler (UT-Tyler), USA, participated in the study: 58 respondents attended UT-Tyler-Main Campus (TYL) and 34 attended UT-Tyler-Houston Engineering Center (HEC). Both campuses had 2.2 male-female student ratios (60 males, 27 females and 5 who preferred not to say), which is higher than the national engineering programme average and closer to the global norm. HEC is located in the heart of a large metropolitan area, whereas TYL is situated in a small rural city. Figure 1 displays the demographic characteristics of the students who took part in the study.

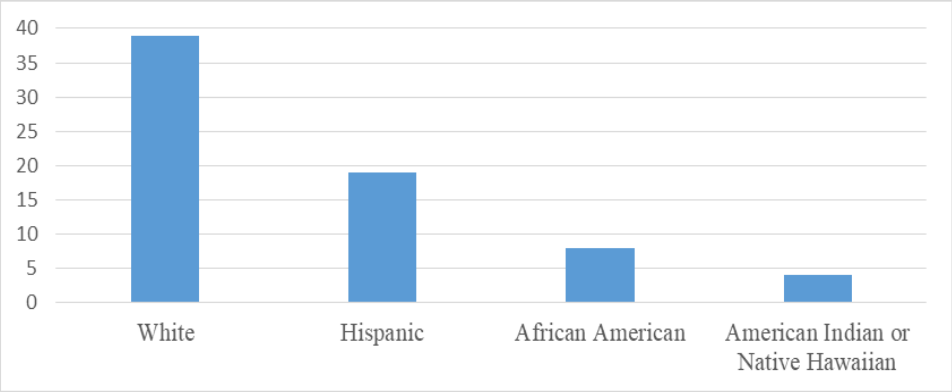

Figure 1: Demographics of participants who responded to the questionnaire.

Method

This study applied quantitative methods. An anonymous questionnaire was distributed on-line to engineering students at UT-Tyler, who were requested to complete it over a period of one week at the onset of the 2022 Spring Semester. Table 1 presents examples of projects.

Table 1: Examples of projects.

Year of study	Subject	Description
Freshman	3D-printed articulated robots and machines ready for controller installation and operation	Final freshman year projects in a graphics course, namely the design and production of a simple robot or a mechanical device with articulated parts.
Sophomore	Course projects	Course-related team projects designed to deepen understanding and apply learned concepts in a project-based learning setup and in the form of a competition.
Junior	Autonomous robot	An autonomous mobile robot based on an Arduino microcontroller and programmed using an app.
Senior	Industry-sponsored projects	Industry-sponsored design and building of projects, including NASA-sponsored devices for space operations.
Graduate	Applied research	Projects including design, simulation, experiments and on occasion products that complement applied research or prove innovative concepts and theses.

The research used a quantitative methodology to examine data of quantitative nature that were gathered from a questionnaire. Throughout the academic year, the students were tasked with the completion of a second, self-report questionnaire.

To evaluate the aptitude of engineering students in systems thinking and soft skills, the researchers conducted an analysis to determine the correlations between different aspects of systems thinking and a range of soft skills. Specifically, the quantitative data was subjected to a Pearson correlation coefficient analysis to examine the relationship between scores on cognitive and soft skills. The 53 self-report statements pertaining to systems thinking and soft skills were categorised into five different categories, as shown in Table 4 (see Findings section).

Instruments

The self-report questionnaire distributed in this study consisted of 53 items that were developed based on the attributes of systems thinking [8][25] and soft skills [26] commonly observed in engineers. The questionnaire used a 5-point

Likert scale ranging from *strongly agree* to *strongly disagree*. Twenty-eight of the 53 statements in the questionnaire pertained to systems thinking, while the other 25 statements focused on soft skills. The questionnaire was validated by two engineering education specialists. The internal consistency of both the systems thinking statements and the soft skills statements, as measured by Cronbach's α (α = 0.831 and α = 0.879, respectively), was determined to be satisfactory. Thus, for example, the statement: *When I am involved in an engineering project, I take into account the interactions (relationships) between my component and components belonging to other team members within the project* indicates a relatively high level of systems thinking. On the other hand, the statement: *When things go wrong in an experiment/project, I have a hard time admitting my mistakes* indicates a relatively low level of soft skills.

Findings

Analysis began by organising the data into five pairs of categories and exploring correlations between systems thinking and soft skills within each of these pairs. Following that, the correlations based on gender and campus were explored.

Table 2 provides a list of the data categories from the 53 statements for both systems thinking and soft skills, as well as the related descriptive statistics (N - number of responses, M - mean (ranging from 1 - low to 5 - high) and SD - standard deviation) for each of these comparisons.

Table 2: Descriptive statistics of components of systems thinking and soft skills (N = 92).

Comparison	Systems thinking	M	SD	Soft skills	M	SD	*r*	*p*
1	Understanding the interactions between components	3.99	0.67	Project management and execution	3.62	1.02	0.62	< 0.01
2	Understanding the big picture	4.18	0.52	Team interaction	4.12	0.61	0.50	< 0.01
3	Implementation and optimisation	3.57	0.31	Organisation and planning	4.20	0.58	0.61	< 0.01
4	Knowledge and management	4.09	0.50	Leadership	4.56	0.53	0.46	< 0.01
5	Knowledge and management	4.09	0.50	Self-efficacy	3.77	0.74	0.36	< 0.01

Pearson correlation coefficients for all comparisons, except the last, i.e. knowledge and management (systems thinking) vs. self-efficacy (soft skills), were positive, moderate and significant, while for the last comparison it was positive, low and significant.

Table 3 presents the Pearson correlation coefficients for the same comparison pairs listed in Table 2, but with students grouped by gender. Pearson correlation coefficients for the male group were positive, moderate and significant in the first three comparisons, and positive, low and significant in the last two comparisons. As for the female group, Pearson correlation coefficients were positive, moderate and significant for all comparisons except the first, for which it was positive, high and significant.

Table 3: Descriptive statistics of components of systems thinking and soft skills by gender.

Comparison pair	Gender	N	Systems thinking		Soft skills		*r*	*p*
			M	SD	M	SD		
1	Male	60	3.96	0.59	3.55	1.03	0.56	< 0.01
	Female	27	4.09	0.80	3.84	1.01	0.70	< 0.01
2	Male	60	4.17	0.48	4.11	0.58	0.43	< 0.01
	Female	27	4.20	0.63	4.05	0.71	0.63	< 0.01
3	Male	60	3.59	0.32	4.22	0.57	0.58	< 0.01
	Female	27	3.56	0.32	4.25	0.59	0.65	< 0.01
4	Male	60	4.07	0.47	4.57	0.49	0.33	< 0.01
	Female	27	4.07	0.55	4.51	0.65	0.63	< 0.01
5	Male	60	4.07	0.47	3.73	0.75	0.29	< 0.05
	Female	27	4.07	0.55	3.82	0.75	0.36	< 0.05

Examining the data from the questionnaire, according to the same comparison pair, this time with students grouped by campus reveals a different picture, as seen in Table 4. Pearson correlation coefficients for the TYL campus were positive, high and significant for the first and third comparisons, and it was positive, moderate and significant for the second comparison. However, for the last two comparisons, Pearson correlation coefficients were positive, low and significant ($p < 0.05$). When looking at the HEC campus, Pearson correlation coefficients were positive, moderate and significant for all comparisons except the last comparison for which it was positive, low and significant ($p < 0.05$).

Table 4: Descriptive statistics of components of systems thinking and soft skills by campus.

Comparison pair	Campus	N	Systems thinking		Soft skills		r	*p*
			M	SD	M	SD		
1	TYL	58	3.95	0.64	3.58	0.97	0.76	< 0.01
	HEC	34	4.06	0.72	3.70	1.12	0.43	< 0.01
2	TYL	58	4.16	0.48	4.12	0.57	0.58	< 0.01
	HEC	34	4.20	0.59	4.12	0.69	0.44	< 0.01
3	TYL	58	3.55	0.32	4.13	.061	0.70	< 0.01
	HEC	34	3.60	0.30	4.33	0.50	0.40	< 0.01
4	TYL	58	4.05	0.46	4.48	0.51	0.23	< 0.05
	HEC	34	4.15	0.55	4.70	0.53	0.77	< 0.01
5	TYL	58	4.05	0.46	3.69	0.72	0.26	< 0.05
	HEC	34	4.15	0.55	3.90	0.76	0.38	< 0.05

DISCUSSION AND CONCLUSIONS

Based on the findings, it is clear that, in general, the correlations between the different categories of systems thinking and soft skills are mainly positive, moderate and significant. Nevertheless, there were some minor differences when groups of students are looked at based on gender and campus (geographical location).

In essence, while systems thinking and soft skills share common traits, such as holistic thinking and an appreciation for complexity, they differ in focus, application, nature and intended outcomes. Systems thinking addresses the dynamics of interconnected systems, while soft skills pertain to interpersonal abilities that foster effective human interactions. Nevertheless, both systems thinking and soft skills are intertwined in various ways in engineering practice/application, and consequently in engineering education.

Uncovering associations between various components of systems thinking and soft skills among engineering students is of great interest due to potential implications for the effectiveness of engineering education and the future success of engineers in the workplace. As mentioned, systems thinking refers to the ability to understand and analyse a complex system as a whole, considering the interactions and interdependencies of its various components, which helps motivate the development of soft skills. Soft skills encompass a range of interpersonal and communication skills, emotional intelligence, teamwork, problem solving and adaptability, which are crucial for both professional success and better system thinking.

In conclusion, there is a moderate and significant association between components of systems thinking and soft skills among engineering students. Developing systems thinking skills can positively influence various soft skills that are vital for a well-rounded engineering professional. Incorporating systems thinking principles into engineering education can enhance students' problem-solving capabilities, interdisciplinary collaboration, ethical considerations, adaptability and overall effectiveness as engineers.

REFERENCES

1. Senge, P.M., *The Fifth Discipline: The Art and Practice of the Learning Organization*. Doubleday (1990).
2. Itani, M. and Srour, I., Engineering students' perceptions of soft skills, industry expectations, and career aspirations. *J. of Professional Issues in Engng. Educ. and Practice*, 142, **1**, 112-117 (2016).
3. Jain, R.K., Sheppard, E., McGrath, E. and Gallois, B., Promoting systems thinking in engineering and pre-engineering students. *Proc. 2009 Annual Conf. & Expo.*, 14-994 (2009).
4. Mouraz, A. and Sousa, A., Promoting *Soft Skills* from the Start of the Engineering Degree and the Case Study of the Special *Projeto FEUP* Course (2014).
5. Sweeney, L.B. and Sterman, J.D., Bathtub dynamics: initial results of a systems thinking inventory. *System Dynamics Review*, 16, **4**, 249-286 (2000).
6. Amissah, M., Gannon, T. and Monat, J., What is systems thinking? Expert perspectives from the WPI Systems Thinking Colloquium of 2 October 2019. *Systems*, 8, **1**, 6 (2020).
7. Baxter, G. and Sommerville, I., Socio-technical systems: from design methods to systems engineering. *Interacting with Computers*, 23, **1**, 4-17 (2011).
8. Frank, M., Knowledge, abilities, cognitive characteristics and behavioral competences of engineers with high capacity for engineering systems thinking (CEST). *Systems Engng.*, 9, **2**, 91-103 (2006).
9. Richmond, B., Systems thinking: critical thinking skills for the 1990s and beyond. *System Dynamics Review*, 9, **2**, 113-133 (1993).
10. Kasser, J. and Mackley, T., Applying systems thinking and aligning it to systems engineering. *Proc: INCOSE Inter. Symp.*, 18, **1**, 1389-1405 (2008).
11. Derro, M.E. and Williams, C.R., Behavioral competencies of highly regarded systems engineers at NASA. *Proc. 2009 IEEE Aerospace Conf.*, 1-17 (2009).

12. Brooks, J.M., Carroll, J.S. and Beard, J.W., Dueling stakeholders and dual-hatted systems engineers: engineering challenges, capabilities, and skills in government infrastructure technology projects. *IEEE Trans. on Engng. Manage.*, 58, **3**, 589-601 (2011).
13. Shekh-Abed, A. and Barakat, N., Challenges to systems thinking and abstract thinking education during the COVID-19 pandemic. *Inter. J. of Engng. Educ.*, 39, **1**, 48-54 (2023).
14. Shekh-Abed, A., Gero, A. and Hazzan, O., Promoting systems thinking and abstract thinking in high-school electronics students: integration of dedicated tasks into project-based learning. *Inter. J. of Engng. Educ.*, 37, **4**, 1080-1089 (2021).
15. Gero, A., Shekh-Abed, A. and Hazzan, O., Interrelations between systems thinking and abstract thinking: the case of high-school electronics students. *European J. of Engng. Educ.*, 46, **5**, 735-749 (2020).
16. Gero, A., Shekh-Abed, A. and Hazzan, O., *Dedicated Assignments as a Means of Advancing Junior Students' Systems Thinking and Abstract Thinking*. In: Auer, M., Hortsch, H., Michler, O. and Köhler, T. (Eds), Mobility for Smart Cities and Regional Development - Challenges for Higher Education, 210-216 (2022).
17. Kossiakoff, A., Sweet, W.N., Seymour, S.J. and Biemer, S.M., *Systems Engineering and the World of Modern Systems*. In: Sage, A.P. (Ed), Systems Engineering Principles and Practice, 3-26 (2011).
18. Johnson, D.W. and Johnson, R.T., An educational psychology success story: social interdependence theory and cooperative learning. *Educational Researcher*, 38, **5**, 365-379 (2009).
19. Goleman, D., Boyatzis, R.E. and McKee, A., *Primal Leadership*. Harvard Business Press (2013).
20. Barakat, N., Engineering ethics and professionalism education for a global practice. *QScience Proc.*, 2015, **4**, 5 (2015).
21. Barakat, N., Plouff, C. and Sebastian, J.R., A model for on-line education of ABET-required professional aspects of engineering. *Proc. 2014 IEEE Global Engng. Educ. Conf.*, 507-514 (2014).
22. de Campos, D.B., de Resende, L.M.M. and Fagundes, A.B., The importance of soft skills for the engineering. *Creative Educ.*, 11, **08**, 1504-1520 (2020).
23. ten Caten, C.S., Silva, D.S., Aguiar, R.B., Silva Filho, L.C.P. and Huerta, J.M.P., Reshaping engineering learning to promote innovative entrepreneurial behavior. *Brazilian J. of Operations & Production Manage.*, 16, **1**, 141-148 (2019).
24. Compton, D.S., High Reliability Leadership: Developing Executive Leaders for High Reliability Organizations (Doctoral Dissertation). George Washington University (2008).
25. Shekh-Abed, A., Systems Thinking and Abstract Thinking among High-school Students Executing Projects Combining Hardware and Software (Doctoral Dissertation). Technion - Israel Institute of Technology (2020).
26. Kantrowitz, T.M., Development and Construct Validation of a Measure of Soft Skills Performance (Doctoral Dissertation). Georgia Institute of Technology (2005).

BIOGRAPHIES

Aziz Shekh-Abed is a lecturer in the Department of Electrical and Computer Engineering at Ruppin Academic Center, Israel. He holds a PhD in engineering education from the Technion - Israel Institute of Technology. His research focuses on project-based learning, systems thinking, abstract thinking, soft skills and metacognition. Dr Shekh-Abed holds an MA in science education and a BSc in technology education, both from Tel Aviv University, Tel Aviv, Israel. He is listed in the Israeli Engineers and Architects Register, under the section of electronic engineering.

Nael Barakat is a professor and chair of the Department of Mechanical engineering at the University of Texas at Tyler, USA. He holds a PhD in mechanical engineering from McMaster University, Hamilton, Canada. His research focus includes energy harvesting, mechatronics, robotics and automation, as well as engineering education, engineering ethics and professionalism. Dr Barakat is a registered professional engineer in Ontario, Canada, and a fellow of the American Society of Mechanical Engineers (ASME). He is also an active programme evaluator with Accreditation Board for Engineering and Technology, Inc. (ABET).