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To be or not to be a systems thinker: Do professional characteristics influence how students acquire systems-thinking skills?

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The increased need for systems thinking has also created a growing need to detect systems thinkers. Systems thinkers grasp a system as one whole made up of interacting elements. They determine what affects the system by applying their ability to identify and understand the interrelationships between the system's components and their impact on each other and on the system as a whole. This article investigates the factors influencing a person's inclination to become a systems thinker. Four different groups had the same systems-thinking learning process. The four groups: working engineering students, full-time engineering students, social workers, and technological college faculty members differ in employment, professional skills, degree of familiarity with their working environment, and position in the organizational hierarchy. The participants completed a questionnaire to assess their systems-thinking capabilities before and after the learning process The questionnaire detected changes in their systems-thinking abilities following this learning and highlighted differences between the groups. The results show that various systems thinking aspects changed in each group following the learning process in a way linked with its different characteristics. Knowing that the diverse characteristics of different groups influence their ability to become systems thinkers enables designing systems thinking training programs adjusted to the characteristics of various groups.

KEYWORDS

systems-thinkers, systems-thinking, systems teaching, learning process, systems engineering skill, engineering skills acquisition

Introduction

Comprehending a system consisting of many components, areas, and topics as one whole is a unique ability of industrial and management engineers. This ability, termed "systems thinking" is crucial not only for industrial and management engineers but also for the entire work world. Therefore, understanding how to improve systems-thinking capabilities is of the highest importance and has been central to researchers and practitioners in the field (Senge, 1991). The professional literature discusses different ways to improve the systems-thinking learning process. However, previous studies have mainly focused on personal qualities required for systems thinking (Frank, 2006), barriers in systems-thinking learning (Beasley, 2012), and methods to evaluate systems-thinking abilities (Koral-Kordova and Frank, 2017). Lavi and Dori (2019) created a common vocabulary for use in science and engineering systems-thinking education, and applied this lexicon to assess systems thinking in pre- and in-service science and engineering teachers.

In the current study, we analyzed the participants' systems thinking *via* a questionnaire initially developed by Frank (2010). Since this questionnaire was originally designed to identify systems thinking among systems engineers, it was necessary to modify and adapt it to the current study population. The adapted version extends the questionnaire to include systems-thinking characteristics in fields other than engineering. The adapted questionnaire underwent several validity and reliability tests to verify its suitability.

The present study aimed to determine the reaction of groups with different attributes to a similar systems-thinking development process and discover whether it has improved their skills.

Research motivation

Systems thinking is currently acknowledged as highly significant. Many 21st Century challenges have uncertain, unexpected, indeterminate, and unknown features requiring complex solutions. In medicine, for example, such challenges include dealing with complex health problems resulting from the COVID-19 pandemic. In addition, global changes have created a new operating environment for logistics systems (Holman et al., 2018). The growth in human interconnections and the complexity of various systems intensify the 21st Century challenges (Mills and Mills Consulting, 2016). In 2015, the United Nations published its sustainable development goals to address global challenges related to poverty, inequality, climate, environmental degradation, prosperity, and peace and justice. These goals require international-level interdisciplinary cooperation. Systems thinking could benefit these goals and should be incorporated into sustainability education (Hurst, 2020).

Systems-thinking principles are particularly conducive to such situations. Dialog helps reveal how people with different cultural characteristics deal with challenging circumstances. Involving people from diverse countries in co-creation and co-designing can yield favorable results (Haley et al., 2021). Multidisciplinary studies with a comprehensive view and systems management approaches that guarantee a significant reduction in resource consumption are cost-effective.

The question arises whether systems thinking can be learned and whether differences exist in the learning process of populations with different characteristics.

Numerous studies dealing with the development of systems thinking focus on the engineering fields, and only a few focus on the social sciences, such as social work and psychology. The current study expands on systems-thinking learning in diverse areas and explores the effects of the learning processes. It examines how factors such as different characteristics, experiences, and positions in the organizational hierarchy affect students' ability to develop their systems thinking. To answer this question, we selected four groups with varying characteristics and analyzed how these characteristics affected their ability to develop systems thinking. The four groups studied were working students, full-time undergraduate students, social workers, and educators. Previous studies have revealed different processes and factors that affect systems thinking. They include experience (Beasley, 2012; Kordova and Frank, 2018; Padhi et al., 2018), systems-thinking practice (Kim and Senge, 1994), teaching systems thinking (Assaraf and Orion, 2005; Camelia et al., 2015), developing a learning culture (Sambrook and Stewart, 2000) and the managerial level, degree of involvement in the working environment, type of employer, and level of education (Nagahi et al., 2020). Below, we examine the effects of these and other factors on the four groups following a systems-thinking learning process. The main issues discussed are the effect of the participants' academic fields (engineering vs. social sciences), their familiarity with the systems they belong to, and their awareness of connections between the system's different components. In addition, our questions examine the weight of position in the organizational hierarchy, the degree of autonomy at work, and organizational functions in acquiring systems thinking. Other factors studied are the need and ability to deal with complex problems and individual and organizational learning processes.

The study examines how the learners' characteristics have affected their approach to the same systems-thinking learning process, and whether previous experience has improved their ability to develop systems-thinking. Its unique strength is in investigating a possible link between learners' characteristics and their ability to develop particular systems-thinking aspects and why. However, the study did not examine the differences in systems-thinking skills pre and post the learning process (Table 1).

Research questions:

1. To what extent does appropriate training improve systems-thinking capabilities among groups with different characteristics?
2. What are the differences in how populations with varied backgrounds acquire systems-thinking skills?

What is systems thinking?

According to von Bertalanffy (1973), different systems can be based on similar laws. Therefore, it is essential to unite various scientific fields and find specific principles that fit a wide range of topics. Senge (1991) presents five areas that must be developed in an organization to make it a learning organization. The fifth area is systems thinking, which stands for having a global perspective without focusing on details. Systems thinking is based on a circular view examining causes and revolutions rather than a linear vision concentrating on discrete events. Four areas influence systems-thinking ability: Personal skills and vision, which define a person's future view of the organization and the means for reaching it; mental models that include assumptions, generalizations, and images affecting a person's understanding of the world and how people operate; shared vision, goals, and values that the organization wishes to instill; and group learning that creates a dialog within the organization that facilitates achieving its goals. Each of the four areas impacts systems-thinking ability.

Several principals define systems thinking as the ability to identify the interactions between different components of a system and their impact on each other and the entire system. Such ability facilitates seeing the system as one entity and understanding what influences its behavior. Another critical component of systems thinking is the ability to solve complex system problems comprehensively without drilling into the details by identifying patterns and interactions. It is an ability to "see the forest and not the trees." To do this, Richmond (1994) claims that systems thinking requires two skills: a vantage point of superiority that defines the viewer's place concerning the system and thought skills that define which aspects are to be considered and which are to be ignored. Systems thinkers can see both the forest and the trees. Frank (2002)

TABLE 1 Approaches to developing systems thinking: what affects systems-thinking development?

What affects systems-thinking development?	Researchers
Effects of teaching tools on the learning process	
The learning processes should include components for the developing of systems thinking	Assaraf and Orion (2005)
Systems-thinking performances improved in the cognitive realm after a course that was based on the ideas of systems thinking	Camelia et al. (2015)
Using specific training programs	Akhtar et al. (2018)
Systems-thinking abilities increase in correlation with one's familiarity with the system.	Deep et al. (2018)
Education for sustainable development and systems thinking can form a common basis for sustainability education worldwide by developing different levels of systems understanding	Holman et al. (2018)
Teaching engineering design methodology	Azemi (2019)
Teaching and practicing systems thinking at a young age	Haas et al. (2020)
Creating a philosophical and theoretical framework relevant to schools or disciplines of science to support the use of systems thinking	Monat et al. (2020)
Having modeling experience affects the ability to learn systems thinking. Learning about food and sustainability contributes to the development of systems-thinking abilities.	Akiri et al. (2020)
Issues related to social and environmental topics need to be linked to systems thinking to support learners' creativity and use of models	Engström et al. (2021)
Integrating design-based research and nature-based learning	Stanfield et al. (2022)
Effects of practice and experience on the learning process	
Practicing systems thinking	Kim and Senge (1994)
Learning from experience is one of the key factors that enable systems thinking	Davidz et al. (2005)
Personal analysis, personality, talent, task management, and experience influence systems thinking.	Davidz (2006)
Experience in engineering-based teamwork in a natural work environment can enable one to apply materials learned in class, collaboration, communication, and planning	Valerdi and Zonnenshain (2012)
Acquiring experience on a wide range of work issues, changing positions, and becoming familiar with diverse technological systems can improve systems-thinking capabilities	Kordova and Frank (2015)
Implementing projects improve CEST	Frank and Koral-Kordova (2016)
Training, diverse work experience, and certain personality traits can improve systems-thinking abilities	Frank and Koral-Kordova (2016)
Diversity of practice areas and experience have an impact on developing skills for systems thinking	Padhi et al. (2018)
Using practical experience	Kordova and Frank (2018)
A project that combines active learning strategies and actual financial data, internal auditing, and project management help to develop systems thinking	Czegledi et al. (2022)
Effects of the organization on the learning processes	
Developing a learning culture in the organization helps to develop systems thinking	Sambrook and Stewart (2000)
Developing systems thinking requires that it be assimilated into core skills and processes in the organization by integrating systems engineering in broad areas	Beasley (2012)
Three-part approach for training managers from a systems point of view: staff management and upward influence; management across the organization; and how a manager sees, understands and acts outside the organization's boundaries	Levy (2017)
A common language between communities can help develop systems thinking	Lavi and Dori (2019)
The level of the managerial role, degree of involvement in the working environment, type of employer, and educational level all have an impact on systems-thinking skills	Nagahi et al. (2020)
Personal effects on the learning process	
Personal analysis, personality, talent, task management, and experience influence systems thinking	Davidz (2006)
Using documentation and correction processes to share mental models within the group and overcome the barriers of personal mental models	Lamb and Rhodes (2007)

discusses the need to understand the complete system, how each component functions as part of the system, and its responsibility for its problems. The internal connections between the components must also be understood.

Kasser and Hitchins (2009) propose a five-tier systems engineering model that illustrates how each level contributes to the level above it and how the constraints of each level affect the lower levels. Meadows (2008) suggests that a system is not only a collection of many parts; rather, it has its own dynamics, goals, and ability for self-esteem and development. The information distributed throughout the organization is essential; it holds systems together and often determines how the system operates.

The knowledge about systems-thinking development has been expanding to include other fields. Also social problems are not scientific in nature, approaching such highly complex problems requires systems thinking. Zulauf (2007) lists several subjects whose development facilitates learning systemic thinking. These include, but are not limited to, sociology, physics, and chemistry. Uskola and Puig (2022) explore preservice elementary school teachers' agency and systems-thinking competencies to propose actions for preventing future pandemics based on the One Health approach.

Wilkerson and Trellevik (2021) show that using systems-oriented methodologies such as systems mapping helps to define problems for sustainability-oriented innovation (SOI) and increases understanding of how the system influences itself over time.

Checkland (1999) proposes resorting to systems thinking whenever there is a conflict between classical "natural science" methods and phenomena of great complexity. He concludes that systems studies must be combined with real problems that require confronting social issues that are not purely scientific. Integrating systems engineering studies into broad areas of the organization can assist in developing systems thinking and solutions.

Systems-thinking tools can also help market researchers re-examine how they interpret and understand the behavior of markets in a complex and changing world. An article by Vargo et al. (2017) lists the changes required to understand the current and future trends in the markets: the separation of micro–macro effects in markets must be overcome to understand how the market behaves as a system, in which a growing number of companies are engaged in creating collaborative value involving multiple players and resources. Systems-thinking sees a market as an ongoing process that reflects responses to changes; therefore, long-term data should be considered rather than data on momentary market patterns.

What are the abilities needed to be a systems thinker?

Frank (2006) defined the "Capacity for Engineering System Thinking" (CEST) and discussed the abilities required to think in a systemic manner (Frank, 2002, 2006). The primary cognitive abilities of CEST are understanding the entire system and seeing the big picture, understanding the internal relationships between the components, understanding the system without going into details, and having multidisciplinary and interdisciplinary knowledge that enables one to work with multidisciplinary tasks. Richmond (1993) found that systems thinking requires dynamic thought defined by circular processing and closed thought-loops that describe continuous processes and the dependencies between them. He added that this thinking must be operational and grounded in reality, which helps identify familiar issues, even in situations that look different. Frank (2010) compared the previous studies that examined the traits a systems engineer needs and concluded that the cognitive ability to understand a system as a whole and have a vision of the big picture are crucial.

A study by Loosemore and Cheung (2015) examined the reasons for the failure of private and public partnership projects. They found that people involved in these projects need to develop new ways of thinking that reflect the project's timeline, complexity, and the interdependence between its elements. Therefore, they must adopt a systems-thinking approach. The factors that affect identifying a practitioner with high systems-thinking abilities are the managerial role level, the environment's complexity, the type of employer, and the educational level required (Nagahi et al., 2020).

How to develop systems thinking?

The following table summarizes the main ideas found in the literature for developing systems-thinking capabilities:

A study of the banking industry in Malaysia and Pakistan found that developing systems-thinking abilities is essential given the challenges facing the banking industry. An informed strategy is needed to develop systems thinking using specific training programs to develop these capabilities in the management team and all employees (Akhtar et al., 2018). The research found that systems thinking can be accessible to many people and that varying methods are appropriate for different participants and situations. Haas et al. (2020) found that systems-thinking practices can be taught even to fifth grade learners if the proper educational process is applied.

Although systems-thinking concepts are well known, they are not always applied in the business environment. Therefore, businesspeople should also develop systems thinking because it helps them to avoid business failures. Monat et al. (2020) suggested creating a philosophical and theoretical framework relevant to schools or scientific disciplines of science to support systems thinking. Existing literature outlines various ways to improve the process of developing systems thinking. The elements of a learning process that can contribute to systems thinking developing include enhancing the ability to identify system components, identifying the relationships between components, focusing on learning-based Research, integrating an outdoor learning environment, and using knowledge integration activities at different levels of the learning processes (Assaraf and Orion, 2005). The changing role of stakeholders in trying to develop a learning culture (Sambrook and Stewart, 2000) is also important. Azemi (2019) suggested teaching engineering design methodology to promote systems thinking. A study conducted by Camelia et al. (2015) examined a course based on the ideas of systems thinking given as part of a curriculum in systems engineering. Students' systems-thinking performance was examined at the beginning and end of the course and was shown to have improved in the cognitive realm but not in the emotional realm. Lavi and Dori (2019) developed a tool to differentiate between various performance and task levels according to different systems-thinking features. Systems aspects of function, structure, and behavior can be applied in various subjects in engineering and science education. Such a tool can create a common language between science and engineering education communities.

Another aspect of systems-thinking development regards teaching to observe processes on a long timeline and from broad perspectives. Levy (2017) proposes a three-part approach for training managers to acquire a broad system vision: vertical management that includes staff management and upward influence; lateral (horizontal) management, referring to management across the organization (colleagues and role partners); and external management where the manager sees, understands, and acts beyond the organization's boundaries with potential business partners, suppliers, and customers.

Several researchers concluded that hands-on experience could contribute to processes for developing learning systems. Experience in handling real problems is helpful, as is familiarity with working in a team whose members come from different disciplines while geing accompanied by professionals from various fields and systems engineering. Suitable tools for learning through experience are case studies and project-based learning (PBL). For example, to narrow the gap between education and practice in accounting studies, students received a project that combines active learning strategies and actual financial data, internal auditing, and project management. It helped them understand the interconnection between business-related disciplines and elements of systems thinking (Czegledi et al., 2022). Kim and Senge (1994) also contend that systems thinking can be practiced. They note that when groups need to work together, they learn together, and group members anticipate new problems and experience them. A study by Kordova and Frank (2018) found that practical experience was of great importance in helping to solve system-related problems, while another study examined the contribution of implementing projects to systems-thinking ability and found that it led to a significant improvement in CEST (Frank and Koral-Kordova, 2016). Integrating design-based research and nature-based learning in biology can expand students' knowledge and lead to systems thinking (Stanfield et al., 2022).

Deep et al. (2018) showed that systems-thinking abilities increase in correlation with one's familiarity with the system. The connection between work experience and systems thinking has been broadly studied. Padhi et al. (2018) found that a diversity of practice areas and experience improve systems-thinking skills. When people are highly experienced in varied fields, they have a greater capacity for systems thinking, and vice versa. In addition, a variety of work issues and different years of experience can compensate for each other. People with few years of work experience often display systems-thinking abilities, indicating that factors other than experience reinforce systems-thinking skills.

Conversely, other studies have found that experience is a factor in developing systems thinking. Frank and Koral-Kordova (2016) found that through appropriate training and diverse work experience, a systems-thinking ability can be improved, especially among people with appropriate personality traits. On the other hand, another study conducted by Koral Kordova et al. (2018) did not find a correlation between the systems-thinking scores and experience of engineers. Davidz et al. (2005) found that learning from experience is a key factor that enables systems thinking.

According to Davidz (2006), at the individual personal analysis level, personality, talent, task management, and experience will influence the ability to be a systems thinker. According to Kordova and Frank (2015), engineers with appropriate personal qualities can improve their systems-thinking capabilities by acquiring experience in various work issues, changing positions, and becoming familiar with diverse technological systems. Learning from experience and working with engineers from different fields are also helpful. For example, Valerdi and Zonnenshain (2012) examined students in a course designed to provide them with the tools required for developing a new product. They found that experience in engineering-based teamwork in a natural work environment allowed them to apply the materials learned in class. In addition, experience enables collaboration, communication, and planning. Within an organization, students learn the professional language and how to conduct themselves in line with the organizational culture, customers, and market conditions.

According to Beasley (2012), systems-thinking development requires its incoporation in core organizational skills and processes, which can be accomplished by integrating systems engineering in broad areas of engineering positions, learning from experience, identifying personal characteristics, and providing the right environmental support. Engström et al. (2021) found that technology textbooks in Sweden do not present systems-thinking topics adequately. They noticed that issues related to social and environmental topics were not linked to systems thinking, risking to impair learners' ability to be creative, interpret, and use models. Education for sustainable development and systems thinking can serve as a common basis for sustainability education worldwide. This can be achieved by developing different levels of systems understanding, such as learning how to work in transdisciplinary teams, learning basics in ecology, and promoting value discussions (Holman et al., 2018).

Individual mental models can influence people's ability to perceive a situation correctly and make appropriate decisions when dealing with systems (Soderquist and Overakker, 2010). However, sometimes decisions should be disconnected from the individual mental models. To reduce the effects of mental models, it is necessary to recognize them and find tools to reduce their impact. Lamb and Rhodes (2007) explored the role of process and culture in enabling or blocking systems thinking at the team and organizational level. Documentation and correction processes can enable sharing mental models within the group, which might help overcome the barriers that personal mental models pose to solving problems regarding sustainability and other fields.

People from different sectors have different abilities to develop systems thinking. Nagahi et al. (2020) found that factors such as the level of the managerial role, degree of involvement in the working environment, type of employer, and level of education all impact systems-thinking skills. To improve these skills, tailor-made learning processes are necessary for each sector. For example, a study by Kordova and Frank (2018) found no significant difference in the systems-thinking skills of participants with different engineering backgrounds. Conversely, when examining the systems-thinking skills of engineers currently employed in various fields, a difference was found between systems engineers and engineers working in other areas, particularly software, hardware, and sales.

Systems thinking and the characteristics of the research population groups

The four study population groups—working students, full-time undergraduate students, social workers, and educators—were selected to represent varied characteristics relevant to learning systems thinking.

According to previous studies, experience can help people develop systems-thinking abilities (Beasley, 2012; Kordova and Frank, 2018; Padhi et al., 2018 and others). Working students must be familiar with the organizations where they work, and increased knowledge about the organization can improve their systems-thinking abilities (Deep et al., 2018). Some workplaces have a learning culture, and people there may participate in various learning processes as part of their work. Expanding knowledge also facilitates increased systems-thinking abilities (Checkland, 1999). People who work in an organization need to know their role within the whole system and understand the interactions between parts of the system and the relationships between them. Past learning supports additional learning in the current process. As Kordova and Frank (2018) found, practical experience helps solve system-related problems.

Social workers are familiar with the system in which they work and have experience working in it. This helps them understand the connections between system components in general. Their professional work requires them to participate regularly in learning processes, including defining objectives and developing educational procedures to achieve the desired result (Flexner, 2001). Camelia et al. (2015) found that it is essential to establish emotional ability when developing systems thinking for engineering.

Educators are have experience working in complex systems. Ebad (2012) who characterized the systems-thinking skills engineers must acquire, noted that they included leadership, systems perceptions, the ability to deal with issues related to the system, understanding the system's structure, and management techniques. Arnold and Wade (2017) also listed the skills that support systems thinking, including understanding how to approach problems, understanding the system from within, its relationship with other systems, forecasting the future, and responding to changes. According to Hill (1992), becoming a manager requires a profound shift in thinking and perception. When a person becomes a manager, he develops interpersonal judgment and learns to deal with pressure. In addition, expanding knowledge enhances the ability to use systems thinking (Checkland, 1999).

Raj and Srivastava (2013) found it challenging to learn new things while working in a hierarchical organizational structure. Full-time students are in a low hierarchical position, with little autonomy, and their status does not allow them to see things differently.

Methodology

Research tool

Our research tool was an adapted version of the questionnaire for assessing the capacity for engineering systems thinking (CEST) developed by Frank (2010), designed to test the systems-thinking ability of engineers. Initially, the questionnaire served to classify and promote engineers and evaluate systems engineering curricula. Previous studies (Frank, 2010; Kordova, 2020) used this questionnaire to explore systems thinking in systems engineers. The present study expanded the research to other populations and explored the prospects of teaching systems thinking before and after the participants underwent a systems-thinking development process. The questionnaire was adapted to suit these particular needs. Verbal changes broadened the systems-thinking references to correspond to varied fields, participants, and aspects of systems-thinking teaching. The adapted questionnaire comprised 28 statements, and participants had to indicate the extent to which they agreed to them on a 1–5 scale (Table 2).

The following measures tested the validity and reliability of the adapted questionnaire:

1. Factor analysis, exploratory factor analysis (EFA), and confirmatory factor analysis (CFA) tested the construct validity of the questionnaire. The confirmatory factor analysis found five factors that characterize systems thinking.
2. An expert analysis examined the content validity of the questionnaire. Three experts in systems thinking evaluated the questionnaire by examining its suitability to the research questions.
3. The most common measure, Cronbach's alpha, considered the mean of all possible split-half coefficients, tested the questionnaire's internal consistency. If all items measure the same variable, a high correlation emerges between all split-half coefficients.

Study design

Research population

The four groups we selected for the Research differ in characteristics such as employment, professional field, level of professional training and work experience, position in the organizational hierarchy and familiarity with the system, and personal and organizational learning.

Research stages

1. The participants completed the questionnaire in their free time before attending a seminar on systems thinking.
2. The four participant groups attended an identical one-session 5-h seminar on systems thinking. Participation was recommended yet voluntary. The seminar aimed to introduce participants from different fields to the components of systems thinking and use identical tools to analyze the knowledge they had acquired. The seminar topics drew on Senge's theory about the Learning Organization (Senge, 1991) and Richmond's approach to thinking skills (Richmond, 1993). Its curriculum included a lecture that explained what a system is, what systems thinking stands for, circular thinking versus linear thinking, principles of systems thinking, and how to change thinking modes. Numerous examples were brought of different processes featuring systems thinking and ones that do not use it. Ways to change the latter if necessary, and practice of various systems-thinking components followed.

TABLE 2 Research population.

Group	Number of participants	Age and gender characteristics	Occupation characteristics	Other features
Working engineering students	49	An equally divided mixed men and women group Average age – 30	40 Industrial Engineering and Management M.Sc. students and nine evening program students in practical industry and management	All the group members work, mostly full-time, and study simultaneously.
Full-time engineering students	47	Equally divided mixed men and women group. Average age—25	Full-time undergraduate industrial and management engineering students	Full-time students, some working in students' jobs
Social workers	15	A majority of women aged 25–55		Social work professionals
Technological college educators	9	An equally divided mixed men and women group aged 35–55		Professional educators with experience in their field and management

The seminar included:

- Examples of systems thinking in various fields such as transportation and organizational structures.
- The importance of understanding the interrelationships within a system.
- Difficulties in learning processes.
- The rules of systems thinking.
- A demonstration of how to changes one's thinking modes to develop systems thinking: presenting the main tools in systems thinking such as feedback loops, a circular vision of problems, seeing the forest and not the trees, and more.
- Patterns of thinking and prototypes of systems thinking.

The entire learning process was accompanied by examples and experiences of the learners dealing with various problems and using systems-thinking tools to solve them.

3. The participants completed the post-seminar questionnaire immediately after the seminar. No time limit was set for filling out the questionnaire, but this had to be done at the seminar location.
4. The researchers used a factor analysis of the responses to group the questions into several factor types that represent common systems-thinking characteristics as defined in the research literature:

I. Every component in the system is part of the system and has responsibility for its functioning (Frank, 2002).
II. Systems thinking involves understanding the interrelationships between system components (Lamb and Rhodes, 2007).
III. Different systems have similar systems characteristics (von Bertalanffy, 1973).
IV. Systems thinking involves changing the mental models associated with the system and its partners (Senge, 1991).
V. To solve problems using systems thinking, one must see the system as a whole and know how to examine the various considerations that govern it (Frank, 2002).

We used ANOVA to determine whether a statistically significant difference exists between the means of the groups. In addition, a Tukey *post hoc* test enabled ascertaining which groups differed from one another.

The questionnaire's result analysis addressed the whole questionnaire and each of the five factors representing systems-thinking characteristics.

Findings

Table 3 displays the indexes for the five factors into which the questionnaire questions were grouped. The table comprises the post-seminar data analysis and the data based on the entire study population. Average values ranged 1–5.

We examined the five systems-thinking factors before and after the seminar to determine if any changes had occurred, how significant they were, whether they occurred to the same degree in all the groups, and whether similar changes occurred for each systems-thinking factor.

The first analysis examined how much knowledge each group acquired over the learning process about each factor. Table 4 shows that the working engineering students and social workers groups significantly improved their average outcomes after the seminar. The average positive change of the working engineering students for factor 1 was $M = 0.11$, and the average positive change for the social workers' group was $M = 0.48$ for factor 2 and factor 4 was $M = 0.52$. The social workers made a greater average improvement than the working engineering students.

The changes following the seminar were also analyzed using *post hoc* tests, which revealed a significant difference in the degree of change between full-time engineering students ($M = -0.017$, $SD = 0.71$) and social workers ($M = 0.48$, $SD = 0.61$) only for factor 2, as shown in Table 5.

A significant difference between groups emerged in factors 2–5 after the seminar. In the test for factor 2, we discovered a significant difference between full-time engineering students ($M = 3.49$, $SD = 0.51$) and social workers ($M = 3.99$, $SD = 0.56$). For factor 3, significant differences appeared after the seminar in the average scores between the full-time engineering students ($M = 3.5$, $SD = 0.52$) and the social workers ($M = 4.05$, $SD = 0.45$). For factor 4, significant

TABLE 3 Post-seminar questionnaire factor indexes.

		Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
N	Valid	120	120	120	120	120
	Missing	8	8	8	8	8
Mean		3.53	3.63	3.68	3.18	3.41
Median		3.56	3.71	3.60	3.25	3.67
Standard deviation		0.35	0.59	0.511	0.52	0.76
Minimum		2.33	2.00	2.40	1.50	1.33
Maximum		4.33	4.86	5.00	4.25	5.00

TABLE 4 Mean pre-post differences, divided by groups and factors.

Group	Factor 1		Factor 2		Factor 3		Factor 4		Factor 5	
	p-value	Mean	*p*-value	Mean	*p*-value	Mean	*p*-value	Mean	*p*-value	Mean
Working students	0.03	0.11*	0.1	0.12	0.2	0.07	0.12	0.09	0.08	0.14
Full-time students	0.2	0.08	0.06	−0.02	0.1	0.04	0.09	0.13	0.06	−0.11
Social workers	0.08	0.19	0.008	0.48**	0.03	0.25	0.007	0.52**	0.1	0.44
Educators	0.08	0.22	0.09	−0.16	0.06	0.18	0.1	−0.08	0.06	0.3

*p-value < 0.05, **p-value < 0.01.

TABLE 5 Change values: factor 2 differences between groups, *Post hoc* tests.

	Factors	Group_n (I)	Group_n (J)	*p*-value	Mean difference (I–J)
Factor 2		Social workers	Full-time students	0.05	0.49*

*p-value < 0.05.

TABLE 6 Post seminar values: differences between groups by factor, *Post hoc* tests.

Factors	Group_n (I)	Group_n (J)	*p*-value	Mean difference (I–J)
Factor 2	Full-time students	Social workers	0.02	−0.50*
Factor 3	Full-time students	Social workers	0.01	−0.50*
Factor 4	Social workers	Working students	0.01	0.48*
		Educators	0.02	0.63*
		Full-time students	0.01	0.47*
Factor 5	Working students	Full-time students	0.01	0.46*
	Full-time students	Social workers	0.01	−0.08*

*p-value < 0.05.

differences were found between the social workers ($M = 3.6$, SD = 0.39) and each of the other groups: full-time engineering students ($M = 3.13$, SD = 0.43), working engineering students ($M = 3.12$, SD = 0.56), and educators ($M = 2.98$, SD = 0.57). In factor 5, significant differences appeared in the average post-seminar scores between working engineering students ($M = 3.53$, SD = 0.7) and full-time engineering students ($M = 3.07$, SD = 0.7), and between full-time engineering students and social workers ($M = 3.84$, SD = 0.82), as shown in Table 6.

Discussion

Table 4 indicates that changes did not occur in all the studied groups, nor in all the systems-thinking factors.

Working engineering students did not show a significant overall change. Most likely, the members of this group do not hold senior managerial positions. Hence, their organizational role does not require understanding and recognizing the effect of the relationships between various components on the system's functioning (factor 2). The seminar did not change their factor 3 results because they were not exposed to other systems. Changes in mental models require understanding these models and how they affect a person's thought processes. As the role of the working engineering students does not require this understanding, the seminar did not improve their comprehension of the mental models and changes required for systems thinking (factor 4). The working engineering students were not in management positions, so the seminar did not change their factor 5 results.

The social workers showed improvement in factor 2 and factor 4. Their professional knowledge derives from various fields, including economics, ethics, religion, and medicine. Despite their high professional awareness, they do not need to fully understand the system of which they make part (factor 1). To assist their clients and develop educational procedures to accomplish the desired result, social workers must understand the interactions between various components in the system (Flexner, 2001). Hence, the learning process created a change in factor 2, understanding the interactions in the system. Factor 3 is not as crucial for social workers as their work focuses on the current status of their clients and does not require an understanding of other systems. Like the working engineering students, management is not a central component of their work which explains why the learning process did not affect factor 5. Social workers' professional education engages, among other things, with the human psyche. Influencing and modifying clients' mental models are part of their work. Therefore, they had to change their mental models (factor 4) as seen in the learning process.

Table 5 shows the differences in the groups' changes following the seminar. The average significant value of change ($p = 0.054$) was found only for factor 2 between full-time engineering students and social workers. The full-time engineering students showed the lowest change and the social workers the highest. Factor 2 relates to understanding the interrelationships within a system. As already noted, this understanding is a professional tool for social workers. Full-time engineering students showed the lowest change in this factor as their role within systems if they work at all, does not require an understanding of system interrelationships. No significant differences in change between the groups emerged for the other factors.

The scores after the learning process (Table 6) show significant differences between the groups in factors 2–5. For example, in the test for factor 2, we discovered a significant difference between full-time engineering students and social workers ($p = 0.022$). Therefore, we may assume that the difference in the average scores after the learning process result from the differences between the groups.

For factor 3, significant differences appeared between the full-time engineering students and the social workers in the average post-seminar scores ($p = 0.004$). Factor 3 regards similar characteristics of different systems. Non-working students or ones holding non-professional temporary jobs are not exposed to different systems. Studying is their primary occupation. If they work, they are exposed only to the system they work in and not to other systems. On the other hand, social workers are in touch with different systems and can learn to recognize their similarities. The seminar developed this understanding and led to a notable improvement in their average scores.

For factor 4, the need to change mental models to create systems thinking, significant differences were found between the social workers and the other groups: full-time engineering students ($p = 0.01$), working engineering students ($p = 0.008$), and educators ($p = 0.017$). One must first understand oneself and the desired changes to achieve changes or improvements in mental models. Hence, the social workers recognized the need to change mental models so as to improve their systems-thinking abilities, and the learning process brought about a change in this factor. In contrast, the other groups came from very different fields and could not understand the benefits of such change. Most notable were the differences between social workers and educators. While academic learning processes aim to generate changes in the learners, they ignore the need for educators to experience changes in themselves.

Factor 5 concerns looking at a system as a whole and considering its governing forces to solve problems *via* systems thinking. Significant differences emerged in the average scores for this factor after the learning process between working engineering students and full-time engineering students ($p = 0.012$) and between full-time engineering students and social workers ($p = 0.002$). The average scores of the engineering students were the lowest since they did not see themselves as part of a whole system even if they worked. Thus, the learning process did not focus on an issue that concerned them. On the other hand, social workers and working engineering students are well aware of the systems they work in, are familiar with the whole system, and can see the various considerations that govern it. Therefore, the learning process improved their acquaintance with this factor more than in the full-time engineering students.

Conclusion

The present study examined the systems-thinking skills of four different participant groups following a seminar that dealt with this field. The measuring tool was a questionnaire adapted from Frank (2010). The participants completed the questionnaire before and after the seminar, to enable analyzing the change the learning brought about. We examined the systems-thinking abilities of each group, compared them, and analyzed their responses, both as one whole and by the five characteristic factors of systems thinking.

The results attained for the individual factors show that the working engineering students achieved an average significant positive change for factor 1 (every component in the system is part of the system and is responsible for its functioning). The social workers achieved an average significant positive change for factor 2) systems thinking involves understanding the interrelationships between system components) and for factor 4 (systems thinking requires changing the mental models associated with the system and its partners). The change in the social workers' average scores was more notable than in the working engineering students.

As outlined above, we found differences between the groups following the learning process. The differences are consistent with the finding of Nagahi et al. (2020) that personal and professional factors impact systems-thinking skills. Possible explanations for the differences found between the groups are:

1. The nature of each group's occupation. Systems-thinking capabilities are influenced by the different fields and issues relevant to each group.
2. The participants' ability to develop systems thinking revolves around the extent to which they can perceive their work as being part of a system, the interactions within the system, and the system's relations with other systems.
3. Systems-thinking abilities improve when the learning process is close to the participants' field of work and likely to help them perform it.
4. The degree of emotional involvement required for the participants to perform their work will impact the change in their systems-thinking abilities.
5. The place and weight of each group within the organizational hierarchy counts. Therefore, learning is more difficult in centralized organizations with a hierarchical culture (Suppiah and Sandhu, 2011; Raj and Srivastava, 2013).

Further research

In this study, we assumed that the seminar was equally suitable for all groups and the differences between them were due to their specific nature. However, the effect of the uniform learning process might not have been the same for all the groups. The different results may be due to the diverse contribution of the uniform process to each group. As Engström et al. (2021) maintain, systems-thinking learning processes must be adapted to the studied problems and areas. Further research might explore the possibility that diverse groups should go through different learning processes.

The studied groups were not all the same size, and group size may have affected the results. This issue also deserves further research.

To further support the findings of this study, it is worthwhile to adapt the questionnaire and test it on other populations with identified demographic data. Since in the current study the tool was a self-report questionnaire, we recommend developing another tool capable of evaluating systems thinking objectively.

Further examination of the correlation between systems-thinking capabilities and social fields such as social work and psychology would probably yield additional insights. Using a questionnaire adjusted specifically for these groups may deepen our understanding of the need to use systems thinking in these areas.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by The institutional Ethics Committee of Ariel University. The patients/participants provided their written informed consent to participate in this study.

Author contributions

AM: conceptualization, methodology, validation, formal analysis, investigation, resources, data curation, and writing—original draft preparation. SK: conceptualization, methodology, validation, formal analysis, data curation, writing—original draft preparation, and writing—review and editing. TG: conceptualization, methodology, writing—original draft preparation, and writing—review and editing. SS: conceptualization, methodology, writing—original draft preparation, and writing—review and editing. All authors contributed to the article and approved the submitted version. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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