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Identifying a Systems Thinker: Matching a Candidate's Systems Thinking Abilities with the Job

Anat Nissel Miller, Sigal Kordova *, Tal Grinshpoun and Shraga Shoval

Department of Industrial Engineering and Management, Faculty of Engineering, Ariel University, Ariel 4070000, Israel; nissela@braude.ac.il (A.N.M.); talgr@ariel.ac.il (T.G.); shraga@ariel.ac.il (S.S.)
* Correspondence: sigalko@ariel.ac.il

Abstract: Systems thinking is an evolving field, and there is growing demand to integrate systems thinking into many fields. The goal of the present study was to develop a new tool for identifying systems thinkers. The study was conducted in two stages. The first, a qualitative stage, consisted of interviews, which were followed by a quantitative factor analysis in the second stage. We interviewed industry executives, lecturers at a technological college for practical engineers, and college students in order to identify the needs for systems thinking. We found that interviewees from different disciplines and roles defined some common requirements for systems thinking, but they also specified some different requirements according to their current professional status. The second stage of the study involved 120 participants with varied professional characteristics. The participants attended a five-hour seminar on systems thinking. After learning about systems thinking, participants answered a questionnaire designed to identify systems thinkers. Factor analysis was then used by the researchers to divide the responses to the questionnaire into five factors that represent common characteristic of systems thinking. Analyzing the responses to the questionnaire according to the five factors facilitates identifying the respondents' knowledge of systems thinking and their ability to use it. Such information is important both for the process of hiring employees and for employee training processes.

Keywords: systems thinking characteristics; systems thinking demands; systems thinker; factor analysis

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1. Introduction

Systems thinking is an evolving field, and there is growing demand to integrate systems thinking into many fields. As this demand increases, so does the need for and importance of identifying systems thinkers. Frank [1] found that systems thinking has four distinct components: knowledge, personality traits, cognitive characteristics, and capability for engineering systems thinking [1]. He then developed the Capacity for Engineering Systems Thinking (CEST) questionnaire [2] as a tool for identifying systems thinking. Following the questionnaire's analysis, conducted previously by Kordova [3], we present here a new way of analyzing and categorizing the questions included in the questionnaire. According to the proposed division, each group of questions represents one component of systems thinking.

Analyzing the answers to the questionnaire makes it possible to identify which characteristics of systems thinking the respondent has and which he/she lacks. This facilitates assigning candidates to positions that require certain aspects of systems thinking or knowing which aspects of systems thinking must be learned.

The outcomes of the study will be of great benefit to different kinds of organizations from both low-tech and high-tech industries. Specifically, this research will benefit organizations in matching a candidate's systems thinking abilities with the right job. The significance of the study is reflected in the process of hiring employees, as well as in employee training processes.

1.1. Systems Thinking Characteristics and Abilities

Systems thinking is the ability to see a system as a whole and at the same time to identify that it is composed of interrelated components. The ability to identify the interrelationships and understand their impact on each other and on the entire system are essential qualities for a systems thinker. Systems thinking traits and the abilities needed to be a systems thinker can be divided to several categories. Senge [4] presented five areas in a learning organization: first, personal skills and a vision that defines the future portrait of the organization and how it can be achieved; second, mental models, including assumptions, generalizations, images, and embedded images that affect how people understand the world and the way they operate in it; third, the shared values, vision, and goals the organization wants to achieve; fourth, group learning that creates dialogue in the organization; and fifth, seeing the whole picture rather than focusing on details. Each of these areas has an impact on the systems thinking ability.

Frank [5] defined CEST as a concept. His various studies [5,6] outline the understandings and abilities required to be a systems thinker. The main cognitive abilities of CEST are seeing the big picture, knowing the internal relationships between the parts of the system, not going into detail, and having multidisciplinary and interdisciplinary knowledge. The ability to "see the forest and not the trees" is an important characteristic of systems thinking [7]. People who have an elevated vantage point, in terms of their perspective on the system and the ability to define which aspects should be considered and which can be ignored, are able to see both the trees and the forest. Frank [2] compared the previous studies that examined the traits required by a systems engineer and found that the ability to understand the system as a whole and see the big picture is a key factor in successful systems thinking. Von Bertalanffy [8] found that the same laws apply to different systems. Increased knowledge helps people to expand their ability for systems thinking. Checkland [9] proposed combining systems studies and using systems thinking in scenarios in which there is a conflict between the methods of natural science and highly complex phenomena, such as social problems that are not purely scientific. Zulauf [10] suggested that learning more about certain fields, including sociology, physics, and chemistry, would contribute to acquiring skills for systems thinking. Additionally, cooperative creation and design between countries are important for dealing with complex situations such as COVID-19 [11].

The internal connections between the components must be understood. The capabilities needed for systems thinking presented by Assaraf and Orion [12] include the need to identify the relationships between components. Yaffe [13] refers to the difficulty caused by not seeing the interrelationships. In many cases, only some parts are identified, while in other instances, they are identified incorrectly; as a consequence, the nature of the overall relationship between the parts and the whole system remains unclear. At times, insufficient attention is paid to the role played by each part of the system and to its contribution to the overall functioning of the system.

1.2. Developing Systems Thinking Abilities

The need for systems thinking is common to many disciplines, but the characteristics required for systems thinking in different areas or situations vary. It is important to identify the need for the specific characteristics in each situation and the relevant factors that influence systems thinking abilities in a specific context. Nagahi et al. [14] found that factors such as managerial level, the need for involvement in the environment, type of employer, and level of education have an impact on systems thinking abilities. However, Koral Kordova, Frank, and Nissel Miller [15] did not find a direct correlation between engineers' scores on systems thinking and the number of years of professional experience they had. Kordova and Frank [16] found that an engineering background does not have an impact on systems thinking, although Hung [17] did find that the combination of knowledge and practical experience helps people use systems thinking. Furthermore, practical experience and diversity of practice areas can contribute to acquiring systems thinking abilities [16,18,19]. Experience and a wide range of work issues, changes in positions, and familiarity with diverse technological systems can also improve engineers' capabilities for systems thinking [20].

According to Kim and Senge [21], systems thinking can be used when groups need to work, experience, and learn together. Valerdi and Zonnenshain [22] found that experience in engineering-based teamwork in a real work environment provides an opportunity to apply materials learned in a classroom. Assaraf and Orion [12] suggest that an outdoor learning environment can facilitate the learning process.

Richmond [23] noted that the ability to recognize familiarity in situations that initially appear different requires thinking that is operational and grounded in reality. In a study conducted by Kordova and Frank [24], experience gained in project implementation supported a significant improvement in CEST. Knowledge of the organization also helps develop systems thinking [25], as does thinking in closed loops that define circular and continuous processes with dependencies between them [23].

People's mental models influence their ability to correctly comprehend situations and make appropriate decisions when dealing with systems [26]. To reduce the effect of mental models, it is necessary to recognize them and then to find tools to avoid their impact. Lamb and Rhodes [27] explored the role of process and culture regulation in enabling or blocking systems thinking at the team and organizational levels. Documenting and correcting processes can help a group share mental models and overcome barriers that personal mental models pose in solving problems.

1.3. The Different needs of Systems Thinking

A hierarchical organizational structure makes it difficult to learn new things [28], and managers should already be skilled in systems thinking before reaching a managerial role. Managers in a system may implement team-building initiatives, such as cross-functional teams, cross-designation teams, and self-management teams, to overcome problems arising from the organizational hierarchy [29]. The systems engineering model of Kasser and Hitchins [30] stresses that each level in an organization should connect to and influence the levels above and below it. Levy [31] proposes a three-stage approach for managers acquiring systems vision: vertically, for team management that includes management and upward influence; horizontally, for lateral management across the organization; and outward to colleagues, partners, and systems leadership outside of the organization's boundaries. This way, managers can have "upward" influence and affect their agendas.

Market behavior is complex and prone to changes. Examining the market with systems thinking tools can help cope with both complexity and dynamism. Understanding how the market behaves as a system and creating collaborative value involves multiple players and resources [32]. People involved in private and public partnership projects need to think in new ways that reflect the timeline, complexity, and interdependence of the project [33]. Haas et al. [34] found that even fifth-grade students can be taught systems thinking practices if the right pedagogical model is found. Monat, Amissah, and Gannon [35] suggest creating the philosophical and theoretical framework of a scientific school or discipline to help use systems thinking in a business environment.

1.4. Research Objective and Outline

The objective of this study was to develop a new tool for identifying systems thinkers, adapted from a questionnaire developed by Frank [2] for assessing systems thinkers. The adjustments to the new questionnaire were made after analyzing interviews and understanding the requirements for systems thinkers. Participants completed the questionnaire twice—before and after a seminar on systems thinking. Factor analysis was used to identify possible connections between the responses to the questionnaire and common characteristic of systems thinking. Our goal was to determine whether the questionnaire can assess respondents' suitability for positions that require systems thinking.

2. Methodology

2.1. Research Tools

In this study, we used two basic tools:

- Open interviews. The interviews were open-ended interviews that were conducted in a friendly manner, as described by Sabar Ben-Yehoshua [36]. The interviewer did not have a defined plan, the conversation was informal, and the questions were spontaneous. Because the conversation was unstructured, there were issues that arose more than once in a single interview. The interviewer could ask the interviewees for further explanations, and vice versa, so that both sides could fully understand each other. That said, it was clear to the interviewer and interviewees that the conversation had a purpose.
- A questionnaire for evaluating systems thinking. The questionnaire was adapted from the one developed by Frank [2]. The original questionnaire for evaluating CEST was developed to assess an engineer's abilities for positions that require engineering systems thinking and as a tool for placing and promoting engineers, as well as evaluating curricula for systems engineers. The adapted questionnaire consisted of 28 statements. Respondents were asked to indicate their degree of agreement with each statement on a scale of 1–5. In the original questionnaire, the respondents needed to choose a statement they agree more with from two optional statements that they received. In the new questionnaire, the statements were adapted to the type of questionnaire of the study and some statements were deleted, so that the questionnaire would be suitable for a variety of fields and not only for engineering fields.

Reliability and Validity of the Questionnaire

The reliability and validity of the original questionnaire [2] were examined in a previous study [15], which calculated two types of reliability: inter-judge reliability and alpha coefficient reliability. Four types of validity were presented: content validity, concurrent validity, contrasted group validity, and constructed validity. To ensure the reliability and validity of the questionnaire, as revised for the current study, it was evaluated by three experts in the field of systems thinking. These experts addressed the clarity of each question and its relevance to the research subject. Clarity is indicative of the questionnaire's reliability, and relevance is indicative of its validity.

2.2. Research Population

- There were 41 interviewees: 6 industry executives, 9 lecturers from the college of technology for practical engineers, and 26 students.
- A study population that attended a seminar of systems thinking included 120 participants, who were divided into four groups that differed in characteristics, such as employment, professional field, level of professional training, work experience, position in the organizational hierarchy, and their familiarity with the system and personal and organization learning. The first group consisted of 40 M.Sc. students studying Industrial Engineering and Management and 9 students in an evening program of practical engineering studies in industry and management. The participants in this group are working students, i.e., students who combine studies and work. The second group consisted of 47 undergraduate students in Industrial Engineering and Management. The participants in this group are full-time students. The third group consisted of 15 social workers. The fourth group consisted of 9 department chairpersons in a technical college for practical engineers. Participants from all four groups answered the verbal questionnaire for assessing systems thinking before and after the seminar.

2.3. Study Design

The study was conducted in two stages. The first stage was qualitative and consisted of open-ended interviews. The second stage used quantitative factor analysis to categorize responses to the questionnaire.

2.3.1. Stage 1: Interviews

- Open interviews were conducted with 6 industry executives, 9 lecturers from the college of technology for practical engineers, and 26 students.
- The interviews were analyzed to find common denominators between the interviewees about the characteristics required for systems thinking.

2.3.2. Stage 2: Factor Analysis

- The study population consisted of 120 participants.
- The participants were divided into groups and each group attended the same five-hour seminar on systems thinking that covered topics from Senge's theory of learning organization [4] and Richmond's approach to thinking skills [23]. The learning process included explanations of systems and systems thinking, circular thinking versus linear thinking, the principles of systems thinking, and how to change people's thought process. The seminar included many examples of different processes characterized by systems versus non-systems thinking and how to change them, if necessary.
- The participants completed the aforementioned CEST questionnaire both before and after the seminar.
- Responses to the questionnaires completed after the learning process were examined using factor analysis in which the questions were divided into five factors.
- All statements on the questionnaire that related to any shared characteristic of systems thinking were grouped with other questions reflecting that factor.

3. Research Results

3.1. Stage 1: Interviews

The purpose of the interviews was to gain an understanding of the interviewees' attitudes and opinions concerning systems thinking: the importance of systems thinking, whether they indeed consider it required, whether systems thinking can be taught, and if so, how can it be taught.

To analyze the results of the interviews, we constructed a list of topics and references that emerged from the answers, and then we examined which of the interviewees addressed these points during the interview (often more than once). As presented in Table 1, there are issues that several interviewees found important for systems thinking, but other issues that only a few considered relevant. The table shows the various topics related to systems thinking and the number of times interviewees in each group mentioned them during the interviews.

Table 1. Interview results.

Subject	Frequency of Mention			
	Executives	**Lecturers**	**Students**	**Total**
Systems thinking can be taught	5	9	3	17
Tools for learning systems thinking				
Systems thinking learning processes: Integration in academic and professional training, understanding the role and influences of various departments on the organization, exposure to the Internet as a learning tool and expansion of knowledge, mentors	13	18	11	42

Table 1. *Cont.*

Subject	Frequency of Mention			
	Executives	Lecturers	Students	Total
Relying on experience on one hand and involving new employees in new ways of thinking on the other hand	5		1	6
Recruitment of suitable people by human resources and identifying the people with systems thinking in the organization	2		2	4
Contact with suppliers and clients	2			2
Organizational culture that enables employee involvement in various fields, team meetings that bring together many engineers with wide ranges of seniority and people with different areas of expertise, exposure to decision-making processes, brainstorming, sitting together	7			7
Managers understand what systems thinking is, direct employees to various positions, and expand the areas of occupation		2	10	19
Personal ability for systems thinking and self-awareness regarding personal abilities	4		5	9
Learning based on different professional points of view and different training processes affect the ability to learn systems thinking		3		3
Main areas in which systems thinking is required				
Management roles	4	4	18	26
Junior workers	2			2
In all fields	3			3
In processes involving workers from different fields	4			4
In systems analysis		1		1
In product development		2		2
In project management		3		3
In areas of uncertainty		1		1

3.2. Stage 2: Factor Analysis

In the second stage of the study, 120 participants attended a five-hour seminar on systems thinking. Before and after the learning process, the participants completed a questionnaire adapted from the CEST questionnaire [2]. We used this tool for in-depth analysis of different characteristics of systems thinking.

The statements that respondents ranked on the questionnaire could be grouped according to the characteristics of systems thinking intuitively or logically. However, we divided them in an objective manner, independent of the person performing the analysis. Therefore, we used factor analysis of the answers given both before and after the learning process. Tables 2 and 3 present the output of the factor analysis. Table 2 shows the total variance explained before and after the matrix rotation, while the rotated component matrix in Table 3 couples the factors and the statements that measure them.

Table 2. Total variance explained.

Factors	Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	5.63	20.11	20.11	4.26	15.23	15.23
2	2.50	8.91	29.02	3.21	11.48	26.70
3	1.94	6.94	35.96	2.04	7.28	33.98
4	1.78	6.34	42.30	1.91	6.84	40.82
5	1.46	5.27	47.57	1.88	6.71	47.53

Table 3. Rotated component matrix.

Statement	Statement no.	Factor/Component				
		1	**2**	**3**	**4**	**5**
When considering improvement processes, check how improvements affect other processes.	2	**0.57**	0.25	0.26	0.19	0.14
When dealing with a specific topic, the smallest detail related to the subject should be understood.	4	**0.33**	0.20	0.26	0.15	
When you encounter a problem at work, you should break the problem down into components.	8	**0.57**		0.23	0.19	0.32
When encountering a problem, first there is a need to understand the context in which it was created.	14	**0.66**		0.1		
To succeed in performing a role, it is important to acquire knowledge even in subjects that are not from the field of major specialization.	16	**0.51**	0.15	0.36	0.14	
Small changes can create significant results.	19	**0.62**			0.21	0.14
It is important to understand how certain components and processes in an organization affect the way things are managed in other components and processes of the organization.	25	**0.69**	0.27		0.29	0.17
It is best to gather as many details and explanations as possible when introducing a new product needed for work for the first time.	26	**0.52**				0.13
To reach a decision, a problem must be examined from different points of view.	28	**0.75**				0.12
When analyzing a process in an organization, it is important to focus on the process itself and not on the way the process integrates with broader processes.	1		**0.67**		0.14	0.13
When working in a team, one important thing is for each team member to perform his/her role as well as possible, regardless of his/her teammates' work.	3		**0.65**	0.19	0.20	
When dealing with a particular field, one should focus on the field itself. There is no need to deal with economic/managerial aspects or any other aspect that will be affected by the task.	5	0.28	**0.67**	0.19		
When presenting a process in the organization, it is better not to deal with the interrelationships and mutual influences between the process components and other processes in the organization.	7	0.25	**0.60**		0.17	0.19

Table 3. *Cont.*

Statement	Statement no.	Factor/Component				
		1	2	3	4	5
A project manager should be a partner, explore the various alternatives to the solution and recommend the chosen solution. He/she does not have to concentrate on implementing a solution recommended by the organization.	11	0.18	**0.50**			
When choosing a manager, it is better to put more emphasis on his/her professional ability, and less on his/her managerial ability.	12	0.37	**0.45**	0.24	0.17	0.38
Each person must specialize in his/her field; having multiple fields may lead to superficial knowledge.	17	0.15	**0.66**	0.28	0.11	
When engaging in a particular process, it is necessary to also understand the role of the other professionals involved in the process.	6	0.32		**0.64**	0.23	
Only project managers in the business world must take project management courses, the other engineers must engage in their field of expertise.	9	0.30	0.30	**0.51**	0.13	0.25
When solving any work problem in the organization, there is no need to turn to superiors, colleagues, or subordinates to clarify questions. If information is needed, you can search for it independently.	22	0.38	0.13	**0.41**	0.20	0.28
Sometimes it is advisable to check what else can be improved, even if it means not meeting the schedule set for the task.	23	0.29	−0.22	**0.40**	0.34	
Ambiguity is an integral part of reality at work.	27			**0.59**		
It is better that the relationship with the customers be handled by those whose job it is.	10	0.20	0.13	0.12	**0.67**	
Compromise and forgo the best solution in terms of performance, for example, for cost–benefit considerations.	13	0.18		0.31	**0.41**	0.16
It is preferable that only those people whose job it is engage in the strategic issues for the organization. There is no need for other people in the organization to be involved.	18		0.39	0.20	**0.52**	0.12
Sometimes it is better to dare and take risks.	24	0.26			**0.60**	
When choosing a workplace, it is best to be part of a team that deals with large civilian or security systems.	15		0.13		0.10	**0.75**
When an employee is part of a project, he/she is interested in knowing what it will look like several years after its completion.	20	0.38	0.22			**0.60**
When solving a problem, "political" and organizational considerations must also be considered.	21	0.31	0.22		0.18	**0.58**

Table 2 presents five factors (or "components") with high eigenvalues or quality scores. Components that have low quality scores are not assumed to represent real traits underlying the questionnaire's 28 items. Factor 1 explained 20.112% of the variance with factor loadings of 5.631, factor 2 explained 8.91% of the variance with factor loadings of 2.495, factor 3 explained 6.935% of the variance with factor loadings of 1.942, factor 4 explained 6.343% of the variance with factor loadings of 1.776, and factor 5 explained 5.27% of the variance with factor loadings of 1.463. Table 2 also shows the total variance explained of each component after the rotation that enables redistribution of the factor loadings over the factors and redefining what the factors represent.

Factor analysis (Table 3) was applied twice, for the answers given before and after the learning process. Therefore, the answers reflect the knowledge that participants acquired during the learning process. Some of the statements were "inverted" to ensure that the respondents answered consistently, regardless of how the statement was presented. After dividing the responses, we identified the common denominators shared by the statements. The factor analysis found the correlation of each statement with each factor (the loading value). Each statement was assigned to a factor according to the highest absolute loading value it received, as shown in Table 3.

The rotated component matrix in Table 3 shows that the first component is measured by statements no. 2, 4, 8, 14, 16, 19, 25, 26, and 28. The second component is measured by statements no. 1, 3, 5, 7, 11, 12, and 17. The third component is measured by statements no. 6, 9, 22, 23, and 27. The fourth component is measured by statements no. 10, 13, 18, and 24, and the fifth component is measured by statements no. 15, 20, and 21.

4. Discussion

During stage 1 of the study, we examined the answers obtained in the open interviews (Table 1) and identified the key issues related to systems thinking. Sometimes, the answers appeared several times in the same interview and were therefore counted multiple times. The idea that systems thinking can be learned was mentioned 17 times during the interviews. There were 42 positive statements about how systems thinking can be learned by being integrated into the training processes for students and workers, learning from other departments and understanding how one department affects others, as well as gaining experience in a variety of areas. On 19 occasions, interviewees said that managers should expand the knowledge of employees and their occupational fields, and 26 times they stated that managers need systems thinking.

Managers said that junior employees need systems thinking and that systems thinking is required in processes involving employees from different fields. Lecturers thought that systems thinking is required in many areas, including product development and project management. They also said that understanding how past thinking affects present events helps people learn systems thinking.

As emerged from the interviews, the desire to teach systems thinking, the ways to learn systems thinking, and the need for systems thinking can be categorized into several factors or characteristics. Systems thinking consists of different components and properties, and it is important to distinguish between the various characteristics and refrain from considering systems thinking only as a "one-size-fits-all" attribute. Analyzing the interviews shows that there are indeed common systems thinking characteristics, but also issues that are required by some groups and not by others. To recognize people with certain characteristics of systems thinking, there is need for a tool that identifies not only general systems thinking ability, but also specific characteristics of systems thinking.

In stage 2, exploratory factor analysis was used to seek connections between the responses to statements on the adapted CEST questionnaire [2] described above, as shown in Table 3. The analysis focused on the questionnaires completed before and after the respondents participated in a seminar on systems thinking. For each group found in the factor analysis, we looked for a common denominator between the statements included in the factor. The common denominator we found was a characteristic of systems thinking that was reflected in the questions included in the specific factor by the factor analysis.

The statements in factor 1 deal with the need to know and understand how each component functions as part of the system. Therefore, we interpret factor 1 as "The responsibility of the components to the system", following Frank's contention [2] that it is necessary to understand the responsibility of system components to the system problems. Troubleshooting will not be successful when disassembling the system into components and finding separate solutions for each component. Kasser and Hitchins [30] propose a model for systems engineering in which each level in the organization contributes to the level above it, while also influencing the lower levels. All parts are responsible for system problems and internal connections between them must be understood.

The statements included in factor 2 refer to the relationships between the components of the system and the need to understand those relationships. Factor 2 is "The interrelationship between the components of the system". One of the cognitive abilities in Frank's CEST [5] was the engineer's need to understand the internal relationships between the parts of the system in order to use systems thinking. Richmond [23] and Senge [4] found that systems thinking in closed loops, which define the relationship between factors in a system as circular and interdependent, is a capability required for systems thinking. Assaraf and Orion [12] found that one skill that helps develop systems thinking is the ability to identify the relationships between components.

The similar systems characteristics of diverse systems are common to the questions included in factor 3, which can be summarized as "The similarity between different systems". Von Bertalanffy [8] claims that the same laws appear in different systems. Expanding knowledge in certain fields can help acquire systems thinking [9,10], and systems thinking is necessary in many areas of existing engineering positions [18]. One of the first conclusions drawn when analyzing the COVID-19 epidemic was that cooperation and knowledge sharing between countries is required for solving complex problems [11].

The statements included in factor 4 indicate that systems thinking involves changing the mental models associated with the system and its parts. Thus, we interpret factor 4 as "Systems thinking and changing in mental models". Mental models determine the way we see and analyze what is around us. They are based on people's assumptions and their life and behavior patterns, but can harm how they see things and make decisions [26]. Mental models influence systems thinking ability, and therefore, the models of people in a learning organization must be considered by the organization [4]. Heisenberg's uncertainty principle means that the observer has a role in the scientific process, and the very fact that he/she is observing the system might affect the system being observed [37]. Lamb and Rhodes [27] found that documenting and correcting processes can help overcome the mental models of group members and create shared systems thinking. Randle [38] suggested that systems thinking is related to verbal intelligence, openness to experience, and complexity of cognitive models.

Factor 5 is "The system as a whole and what affects it". This factor states that in order to solve problems through systems thinking, one must see the system as complete and know how to examine the various considerations that govern it. Yaffe [13] presents the difficulties of not seeing the interrelationships and not paying attention to their role in and contribution to the functioning of the system as a whole. Expanding the view and not isolating the smaller parts of the system can help to see the complete picture of the system [9].

Examining the "blind" division of statements on the questionnaire using factor analysis found that statements belonging to each factor could be attributed to a particular ability of systems thinking, as found and explained by various researchers examining systems thinking. Each set of questions presents a particular characteristic of systems thinking, and the key characteristics are reflected in the various factors.

Figure 1 presents a system model for adapting systems thinking capabilities of a job candidate to the job requirements.

From the interviews, we can see that different expectations from systems are reflected in the five factors that characterize it. Learning systems thinking requires learning from other fields, understanding how one field affects another, and experiencing varied areas of expertise. Knowing that every component in the system is part of the system and has a responsibility for its functioning (factor 1), that different systems have similar systems characteristics (factor 3), and that the internal connections between the components must be understood (factor 2) can facilitate learning. To learn systems thinking, it is necessary to understand the mental models of people (factor 4) and know the best methods for teaching systems thinking.

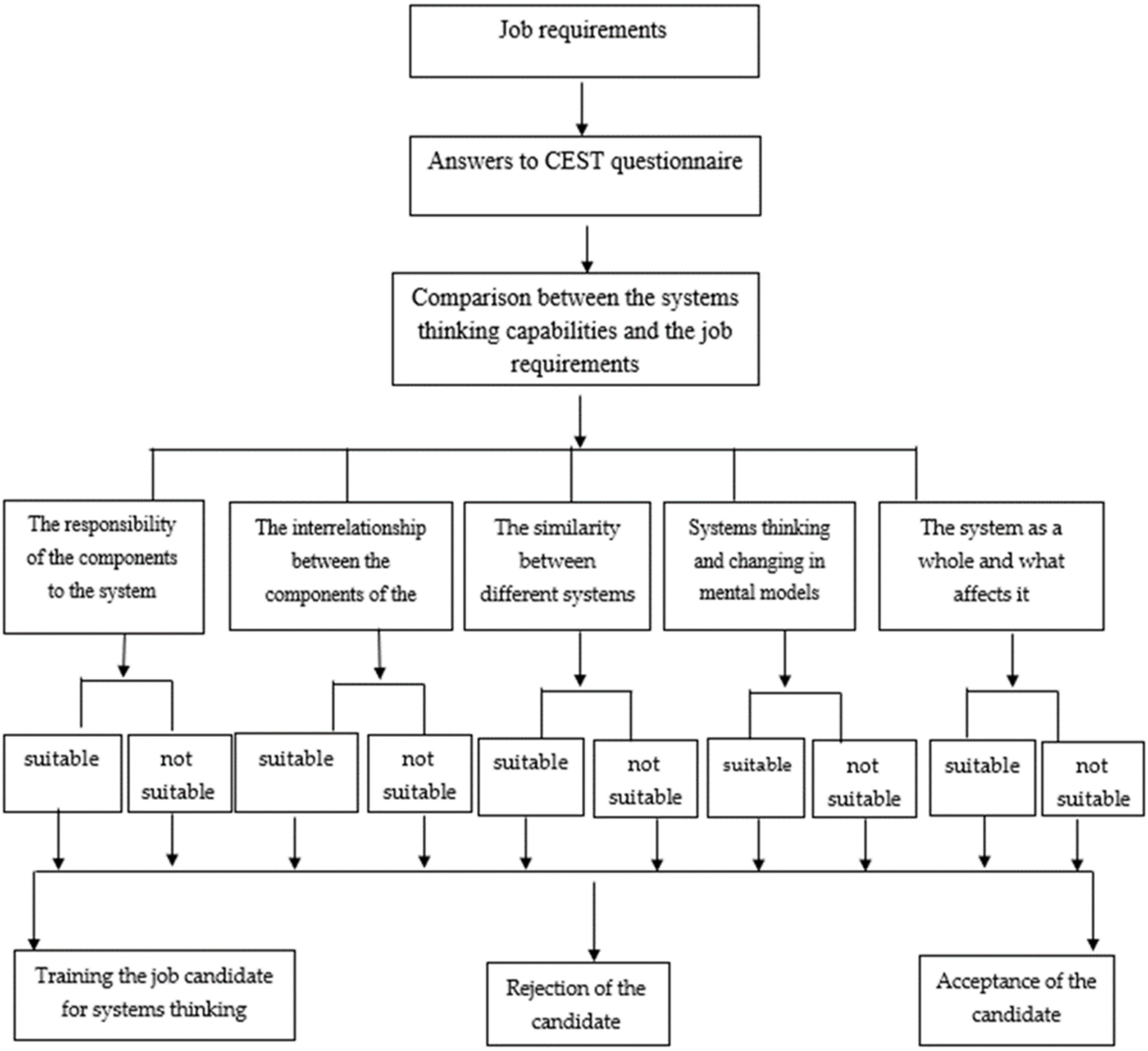

Figure 1. A system model for adapting systems thinking capabilities of a job candidate to the job requirements.

The need for knowing systems thinking in all stages and areas of the organization requires understanding the characteristics of systems thinking, which are expressed in the five factors. To comprehend how past thinking affects events in the present and think about the issue at hand without becoming absorbed in the details, it is necessary to see the system as a whole and know how to examine the various considerations that govern it (factor 5). By categorizing systems thinking through characteristics that can be identified using the statements on the adapted CEST questionnaire, it is possible to emphasize specific requirements and verify whether respondents meet them.

5. Summary

This study consisted of two main stages. In stage 1, we explored the perspectives of lecturers, students, and managers regarding systems thinking, its importance, tools for teaching and learning systems thinking, demand for systems thinking in different fields, and the differences in systems thinking abilities between employees from different fields. In this stage, we used the "open interview" tool, and the interviews revealed that some aspects of systems thinking were shared by all while others were unique to a specific group. This demonstrates the importance of having a tool that can identify different aspects of systems thinking.

The questionnaire for assessing Capacity for Engineering Systems Thinking (CEST) [2] can identify systems thinking. We used a modified version of this questionnaire in stage 2 to create a tool for identifying certain characteristics of systems thinking. A total of 120 participants answered the questionnaire before and after a five-hour seminar on systems thinking. We then conducted factor analysis on the responses to the questionnaires completed before and after the learning process and used the results of this analysis to create an objective division of the statements on the questionnaire into five factors, one for each key characteristic of systems thinking.

We found that some characteristics of systems thinking are not dependent on the person's role in the organization, while others are linked to certain positions. Factor analysis of the systems thinking identification questionnaire divided the questions into five factors, each representing a common characteristic of systems thinking. This, in turn, facilitates identifying the features of systems thinking that characterize each respondent.

The five characteristics of systems thinking we found represented in the factors are:

- The responsibility of the components to the system: Every component in the system is part of the system and has a responsibility for its functioning.
- The interrelationship between the components of the system: Systems thinking involves understanding the interrelationships between system components.
- The similarity between different systems: Different systems have similar systems characteristics.
- Systems thinking and changes in mental models: Systems thinking involves changing the mental models associated with the system and its partners.
- The system as a whole and what affects it: 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.

Dividing the questionnaire statements into groups, each characterizes a specific systems thinking ability and enables us to obtain a broader view of the respondents' systems thinking capabilities. Based on the answers given by the respondents, it is possible to determine which characteristics of systems thinking they know or are aware of. This analysis makes it possible to assess the suitability of the respondents for positions that require systems thinking. If it turns out that there are some characteristics of systems thinking that the respondents do not know, then the analysis of the questionnaire can point to a specific learning process in order to acquire the missing abilities. This is important both for the process of hiring employees and for employee training processes.

The study population consisted of four groups with different characteristics. In this study, there was no reference to how groups with different characteristics are affected by learning processes of systems thinking. In following studies, it is recommended to examine whether there are differences in the acquisition of systems thinking between different groups that study systems thinking. Future studies can investigate how the different characteristics of systems thinking, which were found in the analysis of the interviews and the questionnaire in this study, are reflected in groups with different characteristics.

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