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Developing Systems Thinking in a Project-Based Learning Environment

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Abstract - *As science and engineering projects are becoming increasingly more complex, sophisticated, comprehensive and multidisciplinary, there is a growing need for systems thinking skills to ensure successful project management. Systems thinking plays a major role in the initiation, effective management, and in facilitating inter-organizational tasks. This research assesses the capacity for engineering systems thinking and its contribution in carrying out a multidisciplinary project. The research also reviews the cognitive process through which systems thinking skill is acquired. The study focused on a group of students who have completed their senior design projects in high-tech industry, while their plans were being integrated into existing larger projects in the respective industrial sites. The systems thinking skill of the students was examined according to a questionnaire for assessing the Capacity for Engineering Systems Thinking (CEST). Statistical analysis shows significant differences in the students capacity for systems thinking at the beginning and end of the work (p<0.001). This research demonstrates that systems thinking skills can be improved through awareness and involvement in multidisciplinary projects.*

Keywords – *Systems Thinking; Capacity for Engineering Systems Thinking; Project Based Learning; Structural Equation Modeling.*

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1. Background - The Research Problem

Today's business environment is the outcome of technological, social and economic changes. This environment is characterized by a globalized world economy, fierce inter-organizational competition, the use of innovative management approaches, the availability of information and knowledge accompanied by rapid and inexpensive media, and advanced information systems.

Over recent years, industry has become central and very influential to our lifestyle in the highly developed world. As a result, graduates of the industrial engineering and management disciplines require better training and preparation than in the past. They must be proficient in the many new existing technologies and capable of handling complex information systems.

Industrial engineering and management studies include specialized subjects in Production Management, which expose learners to different approaches and techniques that aid organizational decision-making process, as well as teach basic subjects such as statistics, marketing principles, and economics. The combination of core subjects together with specialized subjects provides learners with a holistic, whole vision - necessary to their professional performance after completing their studies.

Studying and becoming familiar with an organization as a single system comprised of many components is intended to enrich a student's understanding and ability to implement methods for improving the organization and making it more efficient.

The study population included two different groups: senior technology management students who were registered for a 'capstone project' course and 12th-grade high school students who prepared a 'final project' as part of their 'matriculation exam' in the subject of 'industrial engineering.'

As a result of the high school education system's reform, all curricula in technology disciplines were revised, including the industrial engineering and management discipline. An integral part of the new curriculum in this discipline included preparing a 'final project' in a real organization. In this project, the students need to implement important subjects in industrial engineering such as processes planning, quality engineering, operations and production management.

In order to carry out the final project in industrial engineering and management, students must practically apply what they have learned in some of the industrial engineering and management academic subjects, as well as cope with interdisciplinary problems in the field of industrial engineering and management.

The final project's results and findings will then be presented to the organization's management to aid the decision-making process which, in turn, will lead to improved organizational performance.

Project work includes the following: students are required to identify an organization, present a method they want to examine, analyze the organization's performance and its existing operations and marketing system, and recommend ways to improve the current organizational structure, as well as organizational performance, using industrial engineering and management tools. Each project must be carried out in a specific organization in order to provide a practical dimension to the student's work.

During this study, a project-based learning environment was characterized by the industrial engineering and management discipline, and the contribution of performing a final project on students' capacity for engineering systems thinking was examined.

1.1 Research Objective

The research objective was to explore the contribution of performing a final project on students' capacity for engineering systems thinking, and to discuss the processes by which this ability was acquired while carrying out the project.

2. Literature Review

As previously mentioned, this study deals with a final project carried out by students .Therefore, the main topic of the literature review is Project-Based Learning (PBL) and the presentation of a final project in industrial engineering and management. At the next part of the Literature Review, the concept of systems engineering thinking will be presented. The last part includes a concise overview of the research tool to be used to assess the capacity for engineering systems thinking - called the "Tool for Assessing Students' Capacity for Engineering Systems Thinking".

2.1 Project-Based Learning (PBL)

In many areas requiring high-level training, such as engineering, medicine, science and business administration, a Project-Based Learning (PBL) approach is often developed. PBL is an integrative learning environment requiring learners to solve problems using high-level thinking. In this learning environment, students study an authentic problem and examine the motive for carrying out research activities and the organization of concepts and principles.

Many researchers have cited the advantages of Project-Based Learning such as: the possibility of gaining considerable multidisciplinary knowledge, active learning, significant and authentic learning, developing thinking skills, synthesizing (and not just analyzing), developing teamwork skills, gaining experience in the design process, gaining expertise in the "top down" approach, becoming familiar with the importance of optimal design, developing a capacity for engineering systems thinking, becoming familiar with the principles of project management, developing various study skills and improving scholastic achievements (Crawford, Krajcik & Marx, 1999; Frank, Lavy & Elata, 2003; Elata & Garaway, 2002).

Thomas (2000) claims that in the PBL environment students are, in fact, investigating solutions to a problem. They build their own knowledge by active learning, interacting with the environment, working independently or collaborating in teams, while the teacher directs and guides and they make a real product (Hill 1999; 1998).

PBL approach promotes responsibility and independent learning by engaging students in various types of tasks (Hill, 1999).

According to Barak & Goffer (2002) and Frank, Lavy & Elata (2003) teamwork projects performed in PBL environment, enable the student to become familiar with the top-down approach for systems designing.

2.2 Systems Thinking and Engineering Systems Thinking

According to Senge (1994), the method of breaking down a problem into components apparently facilitates the handling of complex tasks and issues, but in so doing, we often lose perception of the whole, larger picture. Systems thinking is required more today than in the past since we are increasingly collapsing under the burden of complexity and the general Information Explosion. Systems are becoming more and more divergent, complex and dynamic.

In his book, The Fifth Discipline, Senge (1994) defines areas that must be dealt with in order to create the "learning organization" – the development of skills and personal mastery by individuals in the organization, identifying mental models used for thinking and decision-making, building a shared vision, developing the ability for team learning, and the fifth discipline – the development of systems thinking. According to Senge (1994), systems thinking is the process of understanding how things influence one another within a whole. Systems thinking involves viewing "structures" placed at the base of complex problems and discerning which changes could bring about significant improvements involving minimal effort and modifications.

Richmond (1994) suggested that systems thinking is "the art and science of making reliable inferences about behavior by developing an increasingly deep understanding of underlying structure" (p. 141). Subsequently, Richmond (2000) used the paraphrase 'forest thinking' to clarify the concept of systems thinking. According to him, 'forest thinking' involves a "view from 10,000 meters rather than focusing on local trees" and "considering how the system influences systems on the other side of the line and how these latter systems influence the former system" (p. 3). In Richmond's (1991) opinion, the adoption of systems thinking occurs when we are standing back far enough – in both space and time – to be able to see the underlying web of ongoing, reciprocal relationships, interacting cycling to produce the patterns of behavior that a system is exhibiting. You are employing a systems perspective when you can see the forest (of relationships), for the trees. You are not employing a systems perspective when you get 'trapped in an event'.

Sterman (2000) considered systems thinking as a way of looking at systems. For him, system thinking is "the ability to see the world as a complex system, in which we understand that 'you can't just do one thing,' and that 'everything is connected to everything else'" (p. 4). However in another context, Sterman saw systems thinking as an ability to act in a certain way: "the art of systems thinking involves the ability to represent and assess dynamic complexity (e.g., behavior that arises from the interaction of a system's agents over time), both textually and graphically" (Sweeney & Sterman, 2000, p. 2). Hitchins (2007) has combined the systems perspective and the systems tools together: "systems thinking is thinking, scientifically, about phenomena, events, situations, etc., from a system perspective, i.e., using systems methods, systems theory and systems tools. Systems thinking, then, looks at wholes, and at the parts of the whole in the context of their respective whole. It looks at wholes as open systems, interacting with other systems in their environment" (p. 17).

Squires and her colleagues (2011) claimed that systems thinking is the ability to think abstractly in order to: (1) incorporate multiple perspectives; (2) work within a space where the boundary or scope of problem or system may be "fuzzy"; (3) understand diverse operational contexts of the system; (4) identify inter- and intrarelationships and dependencies; (5) understand complex system behavior; and most important of all, (6) reliably predict the impact of change to the system.

Systems thinking is a conceptual framework which can utilize different theories, tools and techniques to help construct holistic, contingent perspectives and practices (Joham et al., 2009; Pourdehnad, 2007).

It has been demonstrated in the field of systems thinking that different managerial methodologies are appropriate in different contexts and for reaching different ends. Systems thinking is the right conceptual framework to pursue this kind of contingent managerial design in both practice and theory, since through its synthetic, integrative thinking (Pourdehnad, 2007) we can gain understanding of individual and collective behavior, human and technical alike, that cannot be obtained by analysis alone.

It is obvious that systems research in project management was confined by functionalism and now needs to use more holistic constructs that will not only focus on the creation and utilization of specific tools and techniques under specific situations, but radically change managerial methodology (Pollack, 2007).

According to Bredillet (2013), the four key points demanded in project management are collaborative, engaged, draws on multiple perspectives and enables application.

Ackermann & Alexander (2016) found that there is a growing recognition within the project management community of the need for pluralism of approaches in order to create broader ranging perspectives on projects and thus improve our understandings of them.

Kapsali (2011) found that systems thinking methods provide the flexibility to manage innovativeness, complexity and uncertainty in innovation projects more successfully.

Engineering systems thinking is a higher level of thinking that enables an individual to accomplish systems-related tasks successfully. In order to effectively integrate various systems components within a system, a capacity for higher engineering systems thinking is required. This ability was termed Capacity for Engineering Systems Thinking (CEST) by Frank (2007) and combines knowledge, professional skills, and behavioral components. The main aspect of that ability is the capacity to perceive and understand the overall picture without the need to understand all of the details in advance.

The systems approach is paramount in a complex projects-based environment (Kerzner, 2006). According to Frank and Waks (2001), engineering systems thinking is:

1) The ability to see the whole picture – capacity to perceive and understand the entire system conceptually and with respect to its performance, without understanding the system's details. This ability also includes various synergizing components of the system, as well as the capacity to predict all implications of a change in the system and to propose solutions for system failures.
2) Capacity to implement managerial considerations – capacity to understand and implement managerial considerations that include a comprehensive approach.
3) The ability to acquire and use interdisciplinary knowledge – capacity to cope simultaneously with diverse tasks and use interdisciplinary knowledge to develop an operational approach, to carry out a functional and architectural analysis, to compare systems, to apply the system's planning constraints, to run simulations and to solve optimization problems.
4) The ability to analyze needs and requirements – capacity to understand and analyze a costumer's needs, marketing requirements and future technological developments.
5) To be a systems thinker – capacity to be curious, innovating and self-learning, and to develop and ask relevant questions.

Engineers involved in project development who have a good capacity for engineering systems thinking are capable of: (1) analyzing the needs and requirements of costumers; (2) developing an operational approach; (3) conceptualizing a solution; (4) creating a logical solution and a physical solution (functional and architectural analysis); (5) using simulations and optimization analyses; and (6) implementing systems planning considerations and perform market surveys for which several alternative solutions must be analyzed (Frank, 2002; Davids, 2005).

Systems thinking provides a method with which to describe, analyze, and plan complex systems of diverse types (Holmberg, 2000). Many researchers relate to the need to see the big picture in the problem-solving process. For example, breaking down a problem into components and finding separate solutions for each element only rarely results in an efficient solution (Senge, 1994). In actuality, the opposite is true. Dealing with the entire problem, without breaking it down into parts, results in a more efficient solution in most cases.

A general consensus exists among researchers regarding the importance of systems thinking as a tool to improve organizational performance. Despite this, its use is not developed enough in most organizations (Holmberg, 2000). The main reason for this is the limited number of tools existing in an organization that could increase the practical value of systems thinking. Not enough has been done in the education system either, both in high schools and in academic institutes, to examine the process by which this ability is acquired during the study period and to incorporate tools that could help in the development and evaluation of systems thinking (Kordova & Frank, 2010).

The research tool used to assess the capacity for engineering systems thinking is called the "Tool for Assessing Capacity for Engineering Systems Thinking" (CEST) (Frank, 2007). The objective of this tool is to assess the capacity of individuals being tested in handling tasks requiring systems thinking. This tool could help in selecting and promoting employees, choosing candidates for work, carrying out diagnoses and research, and evaluating curricula.

In the current research study, the tool was used to examine the contribution of performing a final project on the capacity for engineering systems thinking and to map the processes in which this capability is acquired while performing the project. The fundamental assumption lying at the basis of the attempt to develop a tool to assess the capacity for engineering systems thinking is that this ability differs among individuals. In other words, this ability characterizes a person and can be evaluated and predicted. This assumption was verified in a preliminary research study carried out at the Technion – Israel Institute of Technology (Frank, 2002). In this study, abilities were identified that characterized the capacity for engineering systems thinking according to the following division: knowledge, capabilities, and individual traits. In another study (Frank, 2007), the objective of which was to confirm the findings of the pilot research, it was found that the tool for assessing engineering systems thinking capacity is valid for the following aspects: content validity, concurrent validity, and construct-related validity. In addition, a high reliability was found (the result of Cronbach's alpha was 0.855).

3. Methodology

The study examined the development of engineering systems thinking in a project-based learning environment and discussed the question whether this capacity can be developed through experience in PBL approach?

According to PBL approach the student is an active learner who constructs his knowledge on experience. The students were required to construct their knowledge while they were working with their colleagues on a multidisciplinary project. The assumption of this study was that the experience in PBL environment will develop the student capacity for engineering systems thinking.

The study subjects included:

- Forty-two (42) senior technology management students who were registered for the 'capstone project' course in one of the country's academic institute. The students were required to submit a capstone project during one full academic year in the area of industrial engineering and technology management .
- One hundred and eleven (111) 12th-grade high school students from all over the country are studying the Industrial Engineering and Management discipline.
- High school students submitted the final project at two different levels:
- Seventy-three (73) students submitted the final project at a basic level
- Thirty-eight (38) students submitted the final project at an advanced level

The essential difference between the final project at a basic level and a higher level is in the number of topics included in the project, as well as the type of engineering tools used to analyze the findings.

3.1 Final Project in Industrial Engineering and Management

As mentioned before, 12th high schools students have to submit a final project as a part of their 'matriculation exam.' The final project represents an integral component of the curriculum that can be presented at two levels: basic and advanced projects.

<u>Final project in industrial engineering and management - basic level</u>

During working on the core project, the students must analyze organizational processes, including the aspects of quality management and performance improvement. The main stages for performing the core projects are:

- Choosing an organization and the processes on which the project would focus
- Conducting an operational analysis of the organization and its quality control system
- Examining the quality control system and making recommendations for its improvement
- Analyzing a main process in the organization and making recommendations for improving its performance
- Drawing conclusions and making recommendations regarding the organization's work process and quality control system.

The outcomes of the core project include the following:

1. Project proposal
2. Project characterization and work plan
3. Brief description of the organization where the project is being carried out
4. Defining the dimensions and quality indicators in the organization and choosing a quality tool to examine the organization's quality level
5. Examining the organization's existing quality control system using the quality tool
6. Defining the structure of the quality system recommended for the organization
7. Presenting the implementation of the quality approach and the use of tools for improving the quality control system
8. Recommending performance improvements of the main process in the organization using engineering methods and tools
9. Project summary

Figure 1 illustrates the different stages of the final project's implementation process.

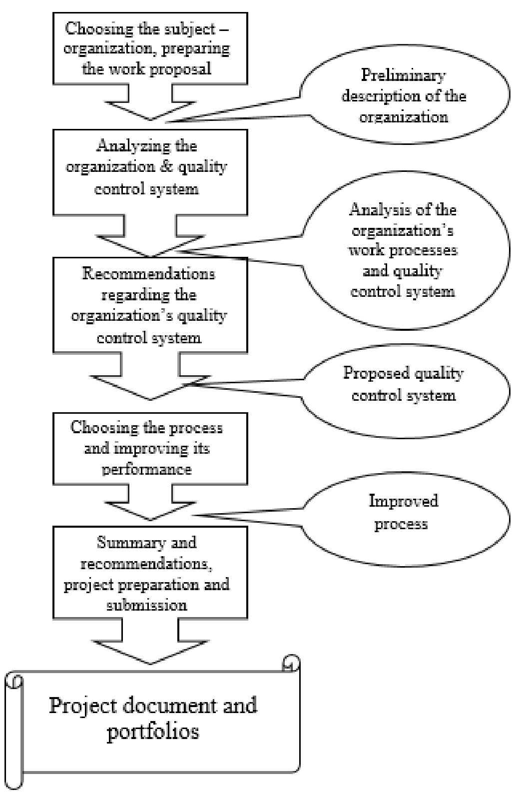

Figure 1. Conducting the final high school industrial engineering and management project

<u>Final project in industrial and engineering management - advanced level</u>

The final project at higher level includes the stages presented in Figure 1; however, in addition, students are required to implement a full chapter from the Production Management subject. Students are also needed to analyze an operational, marketing or economic problem and propose a practical solution to this issue.

3.1 Research Tool: A Questionnaire for assessing students' Capacity for Engineering Systems Thinking

The objective of this tool was to evaluate the survey respondents' capacity for engineering systems thinking. The questionnaire, which was based on an existing questionnaire from the research literature, underwent several revisions and was adapted to the current research objective. The original questionnaire was developed by Frank (2007). This tool was intended to select and promote engineers, preferred work candidates, and analyze and assess systems engineering curricula.

In order to adapt the questionnaire to the current study needs, the statements were revised in such a way to suit the assessment of students' capacity for engineering systems thinking, as expressed during their work on their project. The modified questionnaire was then distributed to three judges, all experts in the field of industrial engineering and management, and experienced in mentoring projects in this area. After analyzing their responses, a revised questionnaire was formulated comprising 31 sets of sentences. For each set, the student was requested to indicate whether:

a. He agreed more with Sentence A.
b. He agreed more with Sentence B.

For example:

A. When I propose a solution to improve an existing situation in the project, I am aware of non-engineering considerations, such as business and economic considerations.

B. When I propose a solution to improve an existing situation in the project, I focus only on operational and engineering considerations.

(The student who has a capacity for engineering systems thinking is expected to choose Sentence A in this example.)

The students were instructed to choose the sentence they agreed with most and were told that there was no "correct" choice. When a research subject chose a sentence that gave evidence of his capacity for engineering systems thinking, he received three points; when he selected a sentence that did not, he received no points. Therefore, the maximum score for the questionnaire is 93 (31 statements / attitudes x 3 points). In order to reduce the tendency for the research subjects to automatically choose an answer out of boredom, fatigue or lack of motivation without reading the contents of the item in full, the questionnaire was formulated in such a way that the capacity for engineering systems thinking was sometimes reflected by statements that appeared in Sentence A, and other times in Sentence B. All of the declarations are based on findings from the study carried out by Frank (2007).

The questionnaire was distributed twice: (1) as a pre-questionnaire at the beginning of the school year – at the beginning of Grade 12 for high school students and the beginning of the fourth year of university studies for the students; and (2) as a post-questionnaire at the end of their studies. The objective was to examine if a change had occurred among the research subjects in regard to their capacity for engineering systems thinking, as a result of performing a project. An additional objective was to see if a difference was observed in this change between senior and young students, and between young students submitting a final project at a basic level and young students submitting a project at an advanced level.

Questionnaire Validity and Reliability - Assessing Engineering Tasks Requiring Engineering Systems Thinking

The questionnaire was structured based on an existing questionnaire developed by Frank (2007). It underwent several revisions in order to adapt it to the current study.

The underlying assumption in this research study is that the area being examined (capacity for engineering systems thinking) is homogenous, whereby an examination of internal consistency between items in the questionnaire is made using Cronbach's alpha.

The reliability of the original questionnaire was verified using Cronbach's alpha and was found to be relatively high (0.855) (Frank, 2007). The result from the revised questionnaire was 0.706 for the 31 items in the questionnaire. After removing four items from the questionnaire, the Cronbach's alpha was slightly higher – 0.765.

Another measurement of reliability examined was interjudge reliability. The questionnaire was distributed to three experts in the field of industrial engineering and management, all of whom had experience in judging final projects in this area. After analyzing their answers, several items in the questionnaire were revised.

A Confirmatory Factor Analysis (CFA) was made in the current study since four factors were already identified in the research study by Frank (2007), which characterized engineering systems thinking. Based on the division by Frank (2007), according to which engineering systems thinking includes four different aspects – knowledge, individual traits, cognitive characteristics, and capabilities – we formulated a suitable structural model in the program using AMOS software.

According to this division, there are four latent variables: knowledge, individual traits, cognitive characteristics, and capabilities. For each latent variable, we matched necessary items in the questionnaire (indicators) and removed items that did not fit any of the latent variables (Kordova & Frank, 2010).

4. Research Findings

An analysis of the questionnaire findings assessing engineering systems thinking capacity was conducted in three stages:

1. In the first stage, an analysis of the findings was carried out using SPSS software, whereby reference was made to the complete questionnaire and to comparisons between the different research groups regarding the overall questionnaire score without relating to the scores for each specific component. The analysis was made using the repeated measures analysis of variance.

2. Following the analysis in the first stage, which related to the complete questionnaire assessing the capacity for engineering systems thinking, the second stage of analysis was made using SPSS software by making a division into factors containing engineering systems thinking components. According to the division presented by Frank (2007) and based on an exploratory factor analysis using SPSS software, we will present an analysis of the questionnaire assessing engineering systems thinking capacity for the following factors: cognitive characteristics, capabilities, individual traits, and knowledge.

3. In the third stage, an analysis of the findings assessing engineering systems thinking capacity was made using AMOS software. Using this software, a confirmatory factor analysis was conducted for items in the questionnaire pertaining to engineering systems thinking; a measurement model was built, whereby relevant elements in the questionnaire were matched to each latent variable based on the factor analysis; and a structural model has been constructed that includes the relationships between latent variables and examines the theory on which building this model was based. In addition, model fit measurements were conducted / calculated using AMOS software.

Stage 1: Questionnaire Findings Analysis - Assessing engineering tasks requiring engineering systems thinking using SPSS software

The questionnaire evaluate the capacity for engineering systems thinking was distributed to two research subject groups: 42 students studying towards a BSc degree in Management and Technology (in parallel to a BSc in Industrial Engineering and Management in universities and other academic colleges) and 111 12th grade high school students from all over the country studying the Industrial Engineering and Management discipline. All the students submitted a final project at the end of the academic year that included subjects and topics from the industrial engineering and management curriculum.

Since the group of 12th-grade high school students was divided into two, the research study actually included three study groups: 42 students, 73 12th grade high school students who submitted a final project at a basic level and 38 12th grade high school students who submitted a final project at an advanced level. The questionnaire was distributed at two points in time: at the beginning of the academic year – before the students starting working on their final project, and at the end of the academic year – after the students had submitted their final project. To analyze the questionnaire findings, we used the repeated measures analysis of variance in the SPSS program.

The repeated measures analysis of variance is suitable for the current research in which two measurements were made for each research subject (pre and post). A repeated measures variance analysis was carried out using the responses of the three research groups in the pre-questionnaire and the post-questionnaire. Variability exists in the current research and a difference in the three research groups was examined; therefore, this is a mixed design within-subjects and between-subjects research. The dependent variable reflecting the difference between repeated measures is called Time; this is the within-subject factor. The questionnaire score at the beginning of the year was called the prefinal_mark and the score at the end of the year the postfinal_mark. A table presenting this variable appears below.

Table 1. Within-subject factors

Time	Dependent Variable
1	prefinal_mark
2	postfinal_mark

The variable reflecting the three research groups is project type (senior students/high school students elementary group/high school students advanced group) and is shown in Table 2.

Table 2. Between-subject factors

		Value Label	N
Project	1	Senior Students	42
	3	High school- basic	73
	5	High school- advanced	38

Below, we present the results of the repeated measures variance analysis in the current research study according to the general linear model.

Table 3.escriptive statistic measurements in the repeated measures variance analysis

	Project	Mean	Std. Deviation	N
prefinal_mark	Senior Students	68.79	13.730	42
	High school- basic	60.41	12.128	73
	High school- advanced	58.66	11.518	38
	Total	62.27	13.018	153
postfinal_mark	Senior Students	77.79	8.418	42
	High school- basic	61.85	10.218	73
	High school- advanced	60.16	11.115	38
	Total	65.80	12.401	153

From Table 3, an essential difference is observed between the students regarding their scores in the pre- and post-questionnaires. The senior students started out with an initial average score that was significantly higher than that of the young students (68.79), and they improved their mean score in the post-questionnaire (77.79). In comparison, the young students in the basic and advanced level improved their initial scores only very slightly (for example, the young students in the basic level group improved their average score from 60.41 in the pre-questionnaire to 61.85 in the post-questionnaire).

In order to validate the repeated measures analysis of variance, we used Mauchly's Sphericity Test to test for sphericity. Sphericity refers to the condition where the variances of the differences between all possible pairs of within-subject conditions are equal. The violation of sphericity occurs when it is not the case that the variances of the differences between all combinations of the conditions are equal.

Table 4 presents the results of this test. When the probability of Mauchly's test statistic is insignificant, we fail to reject the null hypothesis that the variances are equal. Therefore, we could conclude that the assumption has not been violated and we can use regular F tests called Sphericity Assumed.

Table 4. Results of Mauchly's Sphericity Test

Measure: MEASURE_1				
Within-subjects effect	Mauchly's W	Approx. Chi-Square	df	Sig.
Time	1.000	0.000	0	Insignificant

Table 5 presents the results of the ANOVA test and their significance in comparing the scores in the questionnaires at both points in time.

Table 5. Results of repeated measures variance analysis (test of within-subjects effects)

Measure: MEASURE_1						
Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Time	Sphericity Assumed	1,116.543	1	1,116.543	12.374	0.001

	Greenhouse-Geisser	1,116.543	1.000	1,116.543	12.374	0.001
	Huynh-Feldt	1,116.543	1.000	1,116.543	12.374	0.001
	Lower-bound	1,116.543	1.000	1,116.543	12.374	0.001
Time * project	Sphericity Assumed	866.323	2	433.161	4.801	0.010
	Greenhouse-Geisser	866.323	2.000	433.161	4.801	0.010
	Huynh-Feldt	866.323	2.000	433.161	4.801	0.010
	Lower-bound	866.323	2.000	433.161	4.801	0.010
Error (time)	Sphericity Assumed	13,534.736	150	90.232		
	Greenhouse-Geisser	13,534.736	150.000	90.232		
	Huynh-Feldt	13,534.736	150.000	90.232		

The values that we present in Table 5 appear in the Sphericity Assumed row since the Sphericity test was found to be insignificant (see Table 4). In this row, a significant difference was found for the "time" source in the questionnaire score at both time points (F(1,150)=12.374, Sig=0.001). The importance of this is that the influence of time on the questionnaire score is significant for each within-subject group. Similarly, in the Sphericity Assumed row, the interaction between project type and time (time*project) was found to be significant (F(2,150)=4.801, Sig=0.01). This means a significant interaction existed between project type and time when the questionnaire was filled out.

Table 6 presents the results of the ANOVA test comparing questionnaire scores for the different project types.

Table 6. Results of repeated measures variance analysis for various project types of projects

Measure: MEASURE_1					
Transformed Variable: Average					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	1,177,227.307	1	1,177,227.307	7,153.201	0.000
Project	10,047.504	2	5,023.752	30.526	0.000
Error	24,686.026	150	164.574		

From Table 6, we can see that a significant difference exists between the different project types (senior students' projects, young students at the basic level and young students at the advanced level) regarding questionnaire scores (F(2,150)=30.526, Sig=0.00).

In summary, according to the analysis of the questionnaire findings assessing engineering systems thinking capacity using SPSS software, we found that a significant difference exists between the achievements of senior students and those of young students. The senior students started working on their final project with a higher capacity for engineering systems thinking and, in addition, exhibited a more significant improvement in this ability as a result of working on their final project. The questionnaire makes a significant differentiation between the engineering systems thinking capacities of senior and young students.

Stage 2: Questionnaire Analysis - Assessing engineering systems thinking capacity according to different characteristics (cognitive characteristics, capabilities, individual traits, and knowledge)

The questionnaire analysis presented up until now has been general and has not related to categorizing the questionnaire items according to their different characteristics. We will now present an analysis of the questionnaire using SPSS software by dividing the elements into the features comprising engineering systems thinking.

According to a division presented by Frank (2007) and Frank and Kordova (2009), and based on an exploratory factor analysis using SPSS software, the questionnaire was divided into the following characteristics:

- Eleven questions are testing cognitive characteristics (whereby the maximum score is 33 points, 3 points per question when the research subject answers that he is a "systems thinker from the cognitive aspect").
- Six questions testing capability of engineering systems thinking (maximum score is 18 points).
- Nine questions testing individual traits (maximum score is 27 points).
- Five questions are testing knowledge (maximum score is 15 points).

Below, we present the improvement that took place among the senior students regarding each of these characteristics. As a reminder, in the previous analysis, conducted using SPSS software, no significant improvement was observed in young students' capacity for engineering systems thinking over time.

Table 7. Percentage of improvement in each characteristic of the questionnaire, assessing engineering systems thinking capacity among the senior students

Characteristic	Mean score on the Pre-test	Mean score on the Post-test	Difference between the Average Pre-test Score and Average Post-test Score	Percentage of Improvement on the Average Pre-test Score and Average Post-test Score
Cognitive	23.4762	27.3571	3.8809	%16.53
Capabilities	11.7857	11.9286	0.1429	%1.21
Individual traits	21.9286	24.8571	2.9285	%13.35
Knowledge	11.5952	13.6429	2.0477	%17.66

In examining the different characteristics among senior students, the most significant improvement took place in regard to cognitive characteristics (an improvement of 16.53%) and knowledge (17.66%).

In the next stage, we carry out a repeated measures variance analysis for each characteristic separately and relate to three research groups: senior students, young students performing a final project at a basic level and young students performing a final project at an advanced level.

An analysis of the engineering systems thinking questionnaire findings, according to the different characteristics defined by Frank (2007), confirms the findings from the analysis of the complete questionnaire using SPSS software. These results report the following: when comparing the achievements of the different research groups regarding each of the characteristics in the questionnaire (cognitive, capabilities, individual traits, knowledge), a significant difference was also observed between senior and young students. In addition, similar to the findings from the analysis of the complete questionnaire, no significant difference was found between the groups of young students (those at the basic level and those at the advanced level). However, it is important to mention that regarding the cognitive and knowledge characteristics, young students studying at the core level had an advantage over young students studying at the advanced level, even though this benefit was not significant. The largest improvement among young students at the higher level was observed in relation to the capabilities characteristic.

Stage 3: Questionnaire Findings Analysis - Assessing engineering systems thinking capacity using Structural Equation Modeling – SEM with AMOS software

During this research study, after performing an analysis of the questionnaire using SPSS software, the need arose to carry out an additional analysis that related to the variables comprising the questionnaire. This analysis was conducted using AMOS software. The objective of AMOS software is to graphically present a system of equations expressing the relationships between variables, and giving numerical values to these relationships, thereby providing a model summarizing the system of assumptions. In addition, the software indicates the model's quality, thus enabling confirmation of the study's theoretical basis, using a confirmatory factor analysis. This analysis further allows us to confirm the exploratory factor analysis made using the SPSS software. The significant advantage of using AMOS software is in drawing a graphic model that reflects the saying "one picture is worth a thousand words." The variables defined in the software could be theoretical measurements (represented by an oval shape) or observational measurements (represented by a rectangular shape), and the relationships between them – a causal connection (one-ended arrow) and a non-causal relationship (double-ended arrow). When we want to verify indirectly-observed phenomena, such as engineering systems thinking, they must be measured using predictive indicators. Engineering systems thinking is a theoretical latent value (hidden) that cannot be predicted directly (the construct is presented in Figure 2), while questionnaire items are predictive indicators (boxes X3, X2, and X1 – the predictive indicators are numbered according to questionnaire items that match the significant latent variable). The values of e1, e2, and e3 represent the statistical errors.

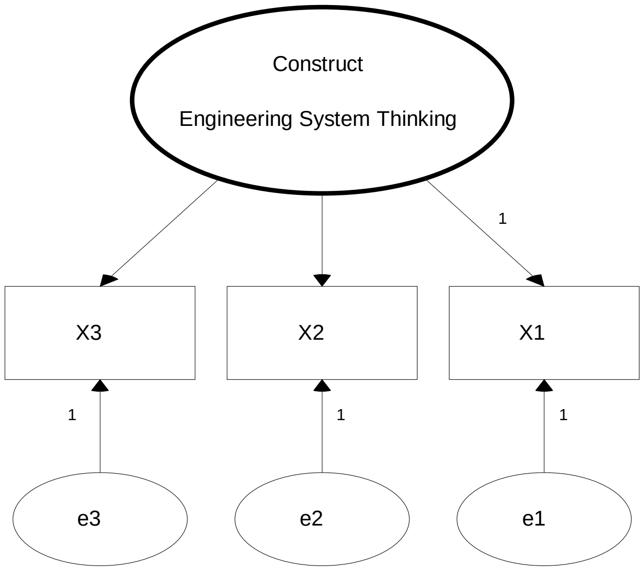

Figure 2. Graphical presentation of the model using AMOS software

Based on theoretical-philosophical considerations, we can assume that the underlying engineering systems thinking variable existed before the predictive indicators. From here, the relationship between the latent variable and the indicators is a definite causal relationship. Using the analysis made with AMOS software, we can estimate the extent to which the latent variable explains each indicator. We attempt to find saturated items/indicators in the latent variable so that we can explain a large part of the variances in these items using the hidden variable.

Relying on the division by Frank (2007), according to which engineering systems are thinking includes four different aspects – knowledge, individual traits, cognitive characteristics, and capabilities – we developed a suitable structural model using the software. According to this division, there are four latent variables: knowledge, individual traits, cognitive characteristics, and capabilities. We matched related items in the questionnaire to each of these latent variables. Each aspect/latent variable of systems thinking includes some of the following components:

Knowledge
- Interdisciplinary and multidisciplinary knowledge
- Extensive experience in dealing with systems tasks, technical experience
- Education and knowledge in systems thinking

Individual Traits
- Managerial skills
- Group leadership
- Excellent interpersonal skills, building relationships of trust with interested parties, excellent communication skills, the ability to "read" people
- Self-study skills, personal reflection
- Desire to deal with systems, a strong desire to succeed
- Perceiving failures and mistakes as challenges, decisiveness, tolerance to difficulties
- Self-confidence and personal motivation

Cognitive Characteristics
- Understanding the whole system, seeing the big picture
- Creative thinking
- Understanding the system without being familiar with all of its details, tolerance to situations of uncertainty
- Understanding the synergy between different systems
- Curiosity, innovation, originality, invention, promotion
- Asking right questions
- Placing limits
- Considering non-engineering factors such as economic, commercial and political factors

Capabilities
- Ability to carry out an analysis of requirements
- Abstract thinking and capacity to develop the solution
- Functional analysis
- "Seeing the future," vision of the future
- Use of simulation and engineering tools
- Optimization
- Resolving system failures and problems
- Ability to offer several solutions to a problem

It is worth mentioning that these components were developed originally in order to analyze the engineering systems thinking the capacity of systems engineers, as opposed to other types of engineers. In this research study, the examination of engineering systems thinking capacity was made with respect to students. Therefore, some of these components are not relevant to the research groups under discussion. As previously mentioned, the questionnaire is assessing engineering systems thinking capacity was adapted to the research group, which included young and senior students, and was comprised of items affecting engineering systems thinking to pertain the work of the students on their final year projects.

Since we measure a general engineering systems thinking variable using questionnaire items, and since we are not dealing with a pure science, it is reasonable to assume that the measured variables include errors. In measuring the predictive indicators X1, X2, X3…, we looked for covariance. Whatever is not common among these indicators is defined as an error, which is measured on the same scale as the indicators. The model's predictive validity is limited by the reliability of the indicators; that is, reliability represents an upper boundary for validity. We cannot obtain a higher prediction level from the reliability of the indicators. This means that if we measured indicators that have a low-reliability level, their relationships with the relevant latent variable would also be low. Similar to the factor analysis, each item (indicator) is loaded with a latent theoretical variable. We would like to verify how each theoretical variable explains the item. In the current study, we verify the actual expression of engineering systems thinking in the questionnaire's items or, in other words, how "loaded" each questionnaire item is, with respect to the different aspects of engineering systems thinking.

Using AMOS software involves two stages. In the first stage, a measurement model is built based on an analysis of factors that matches relevant items in the questionnaire to each underlying value. At this stage, we test the actual measurement. In the second stage, a structural model is built, which includes the relationships between the latent variables and, in actuality, tests the theory on which the model is based.

1) Building the Graphic Model

In order to build a visual model that includes four latent variables representing different aspects of engineering systems thinking, we initially built four simple models separately for each latent variable: knowledge, individual traits, cognitive characteristics, and capabilities. We will present each model together with its matching latent variable.

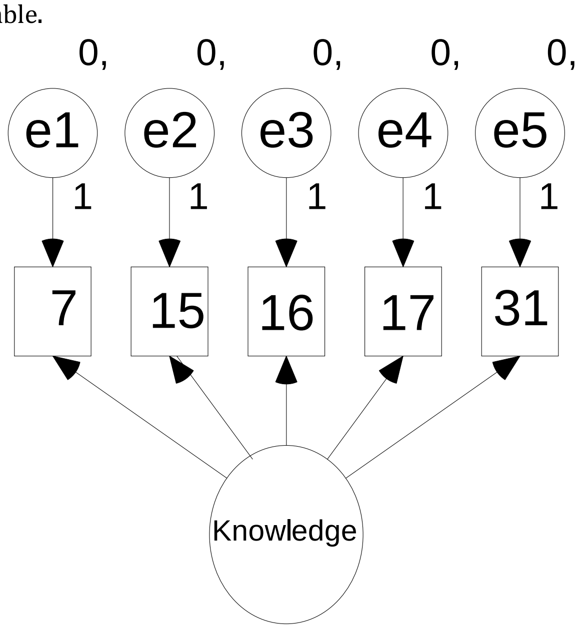

Figure3. Graphical presentation of the latent "knowledge" variable

Questionnaire items (indicators) matching the latent "knowledge" variable are as follows:

Question 7 – knowledge of technological/engineering aspects of the project

Question 15 – knowledge of areas outside the Production Management area

Question 16 – multidisciplinary knowledge, general knowledge, and understanding several areas of engineering

Question 17 – knowledge of project management, cost management, schedule, formation management, management models

Question 31 – knowledge of organizational systems analysis, studies in management areas

Below are data of the loading level of these items on the latent "knowledge" variable (these are the values that appear in the output of AMOS software called Standardized Regression Weights). In addition, Squared Multiple Correlations are given for each item. For example, the item appearing in Question 7 has a Standardized Regression Weight in the latent "knowledge" variable of 0.559, where (0.559)2 = 0.313; that is, 31.3% of the variance of Question 7 originates from the latent "knowledge" variable. A high loading level means that the latent "knowledge" variable clearly explains the relevant questionnaire item.

Table 8. Squared Multiple Correlations of items belonging to the latent "knowledge" variable

Item Number	Standardized Regression Weights	Squared Multiple Correlations
Question 7	0.559	0.313
Question 15	0.464	0.215
Question 16	0.478	0.228
Question 17	0.446	0.199
Question 31	0.506	0.256

Below are the model fit indices we received in this model:

Table 9. Model fit indices of the latent "knowledge" variable

P-Value	χ^2	Degree of Freedom (df)	NFI	TLI	RMSEA
0.664	3.232	5	0.953	1.06	0

TLI and NFI model fit indices with values exceeding 0.9 are considered to be useful indices. In this model, we received high values for these two indices (TLI=1.06, NFI=0.953). An additional fit index presented here is the RMSEA index, which is considered good if its value is less than 0.08. We received a 0 for this value. From this, we can conclude that the model presenting the latent "knowledge" variable is found to be suitable for the data; that is, compatibility exists between the expected and observed values.

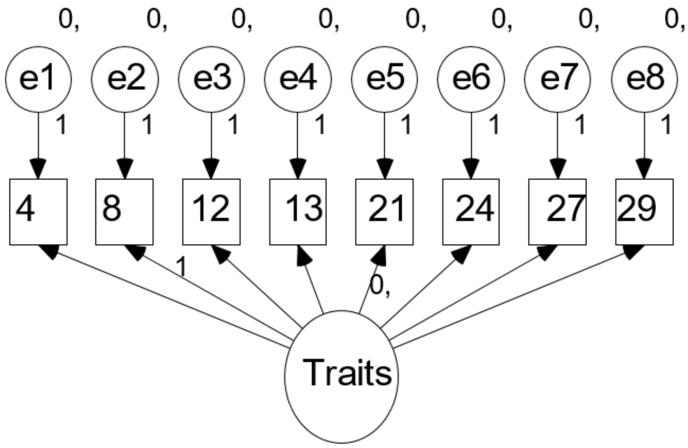

Figure 5. Graphical presentation of the latent "personal traits" variable

Questionnaire items (indicators) matching the latent "personal traits" variable are as follows:

Question 4 – willingness to work in a team while engaging a partner in the project work

Question 8 – personal preference to also focus on topics that are not core subjects of the subject

Question 12 – future desire to be involved in a management discipline as team head, project manager or area manager

Question 13 – preference to be part of a team carrying out the final project as a group (and not individually)

Question 21 – future preference to be involved in management and incorporate different interdisciplinary engineering areas

Question 24 – tendency to participate in class discussions affecting the determination of future directions in the business world

Question 27 – desire and preference to lead a team in carrying out a task

Question 29 – willingness to meet the schedule required to complete the final project

Below are the model fit indices we received in this model:

Table 10. Model fit indices of the latent "personal traits" variable

P-Value	χ^2	Degree of Freedom (df)	NFI	TLI	RMSEA
0.473	19.755	20	0.856	1.003	0

From the table, we see that the TLI fit index exceeds 0.9, but the NFI fit index is very close to 0.9. The value of the RMSEA fit index is 0 (less than the 0.08 value required).

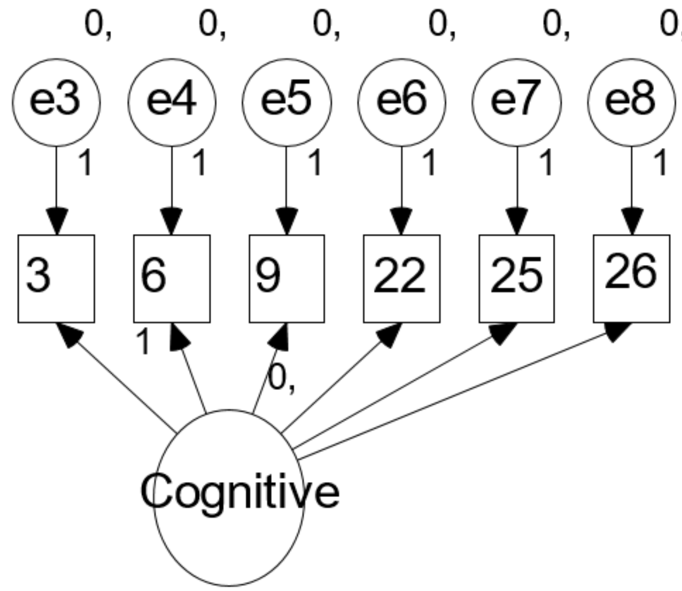

Figure 6. Graphical presentation of the latent "cognitive characteristics" variable

Items in the questionnaire (indicators) matching the latent "cognitive characteristics" variable are as follows:

Question 3 – dealing with combinations and integrations of systems/products/processes during the final project

Question 6 – relating to economic and managerial aspects of the project beyond the operational/engineering areas presented in it

Question 9 – checking the possible implications of changes in the organizational system systemically, economically and otherwise

Question 22 – working on a final project that includes/encompasses several study subjects from the discipline

Question 25 – awareness of non-engineering considerations such as commercial and economic considerations, welfare considerations, business advantages, profitability analyses, etc.

Question 26 – taking political and organizational considerations into account, while providing a solution to the problem being examined in the final project

Below are the model fit indices we received in this model:

Table 11. Model fit indices of the latent "cognitive characteristics" variable

P-Value	χ^2	Degree of Freedom (df)	NFI	TLI	RMSEA
0.098	14.749	9	0.706	0.728	0.065

From the table, we see that the TLI and NFI fit indices do not exceed 0.9. However, the value of the RMSEA fit index is 0.065 (less than the 0.08 value required). It could be that the reason we received fit indices that do not meet the necessary criteria is because we chose items belonging to the latent "cognitive characteristics" variable.

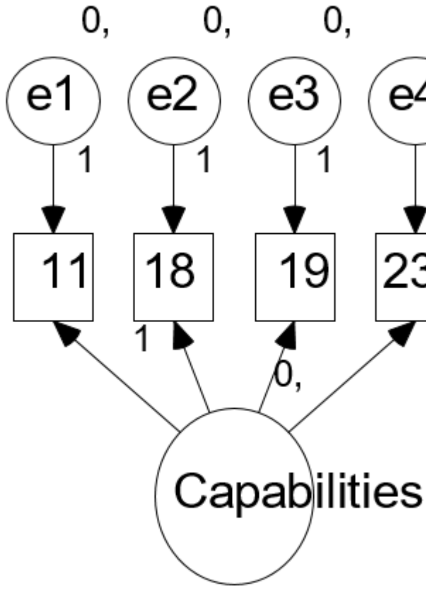

Figure 7.Graphical presentation of the latent "capabilities" variable

Questionnaire items (indicators) matching the latent "capabilities" variable are as follows:

Question 11 – capacity to find a solution to a problem by "bypassing" the problem

Question 18 – capacity to understand the client's needs and requirements

Question 19 – capacity to analyze the customer's needs, requirements and preferences

Question 23 – the ability to apply cost-effective considerations

Below are the model fit indices we received in this model:

Table 12. Model fit indices of the latent "capabilities" variable

P-Value	χ^2	**Degree of Freedom (df)**	**NFI**	**TLI**	**RMSEA**
0.211	3.107	2	0.838	0.749	0.06

From the table, we see that the TLI and NFI fit indices do not exceed 0.9. However, the value of the RMSEA fit index is 0.06 (less than the 0.08 value required). It is worth mentioning that while building the different models presented above, we removed the following items from the questionnaire: Questions 1, 2, 5, 10, 14, 20, 28 and 30. These items were removed since the loading of each was very low (less than 0.2); removing them should increase the questionnaire's overall reliability.

2) Building the Structural Model

After presenting a separate model for each latent variable that includes the relevant items, we can present the structural model, which includes the relationships between latent variables and enables verifying the theory upon which the model is based (Frank, 2010). The structural model presents relationships between the variables – knowledge, individual traits, cognitive characteristics, and capabilities – that present different aspects of engineering systems thinking. Below is the structural model, as built using AMOS software.

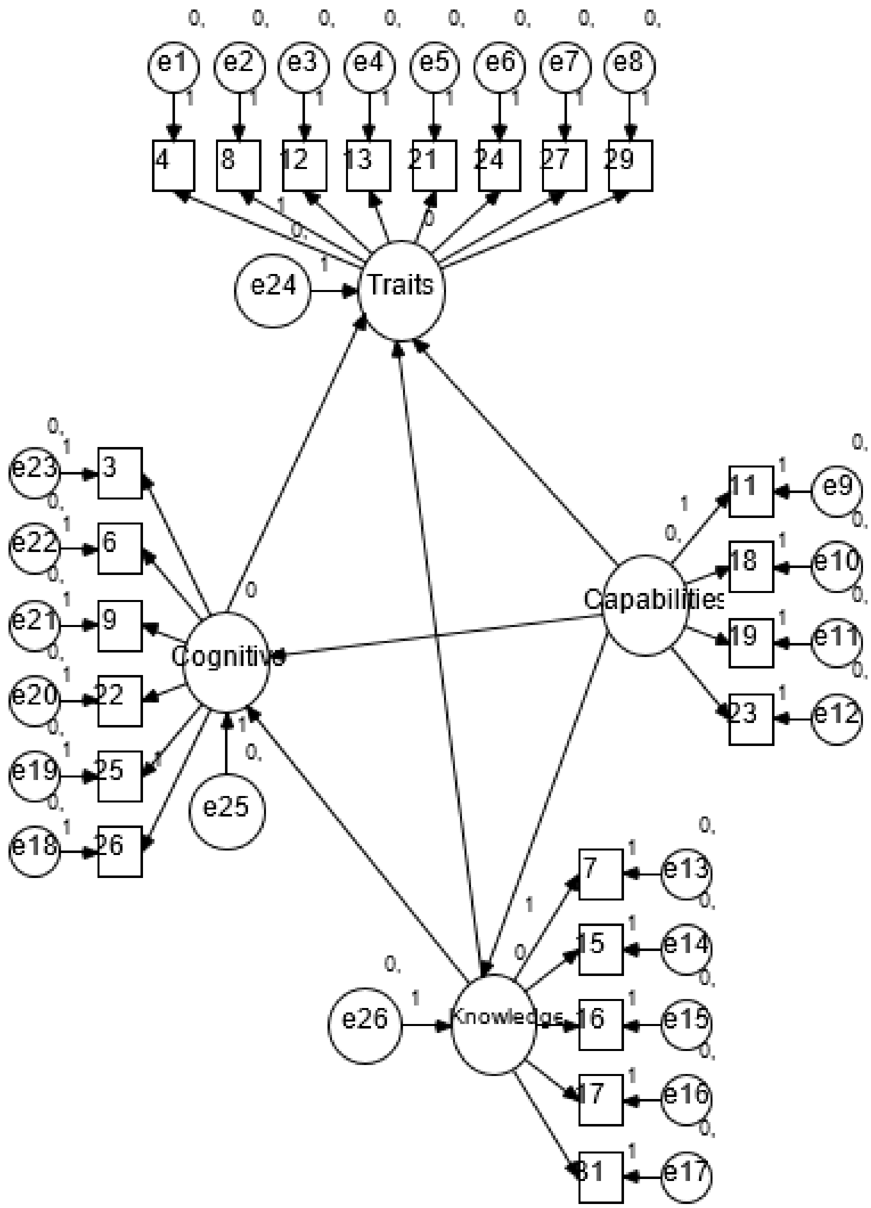

Figure 8: Combined model

The exogenous variable in the model is "capabilities". Arrows start out from this variable and point towards the endogenous variables. In the model presented above, these are the variables of individual traits, knowledge and cognitive characteristics.

Below are the model fit indices we received in this model:

Table 13. Combined model fit indices

P-Value	χ^2	Degree of Freedom (df)	NFI	TLI	RMSEA
0.002	289.585	224	0.515	0.785	0.044

From the table, we see that the TLI and NFI fit indices do not exceed 0.9. The value of the RMSEA fit index is relatively low (0.515). However, the value of the RMSEA fit index is 0.044 (less than the 0.08 value required). In examining the quality of the model received, one should relate to the relatively small sample size (from an overall sample of 153 students/pupils), the fit of items in the questionnaire for pupils/students, the fit of elements in the questionnaire, the different latent variables, and more. In order to improve the current model we use specification search which is not include in this article.

5. Discussion

5.1 The Categories Comprising Engineering Systems Thinking

In an analysis carried out in this research study, we relied on the division by Frank (2007), according to which engineering systems thinking includes four different aspects: knowledge, individual traits, cognitive characteristics, and capabilities. Each aspect of engineering systems thinking has several components. Below, we will present these components as expressed in the questionnaire assessing engineering systems thinking capacity used in this research study.

Table 14. Comparison between the theoretical components of engineering systems thinking aspects and these elements in the questionnaire items, assessing engineering systems thinking capacity

Aspect	Theoretical Components of the Aspect	Elements of the Aspect as Expressed in the Questionnaire Items
Knowledge	Interdisciplinary and multidisciplinary knowledge	Knowledge of technological/engineering aspects of the project, multidisciplinary knowledge, knowledge in project management, cost management, management models, organizational systems analysis (Questions 7, 15, 16, 17, 31)
	Extensive experience in dealing with systems tasks, technical experience	
	Education and knowledge of systems thinking	
Individual traits	Managerial skills	Future preference to be involved in management and to incorporate different interdisciplinary engineering areas; future desire to participate in a management discipline as team head, project manager or area manager (Questions 12, 21)
	Group leadership	Willingness to work in a team while engaging a partner in the project work (Questions 4, 27)
	Excellent interpersonal skills, building relationships of trust with interested parties, excellent communication skills, ability to “read” people	Preference to be part of a team carrying out the final project as a group (and not individually) (Question 13)
	Desire to deal with systems, strong desire to succeed	Personal preference to also focus on topics that are not core topics(Question 8)
	Perceiving failures and mistakes as challenges, decisiveness, tolerance to difficulties	
	Self-confidence and personal motivation	Tendency to participate in class discussions affecting the determination of future directions in the business world; willingness to meet the schedule required to complete the final project (Questions 24, 29)

Aspect	Theoretical Components of the Aspect	Elements of the Aspect as Expressed in the Questionnaire Items
Cognitive Characteristics	Understanding the overall system, perceiving the big picture	Working on a final project that includes several study subjects from the discipline (Question 22)
	Creative thinking	
	Understanding the system without being familiar with all of its details, tolerance to situations of uncertainty	Checking the possible implications of changes in the organizational system systemically, economically and otherwise (Question 9)

	Understanding the synergy between different systems	Dealing with combinations and integrations of systems/products/processes during the final project (Question 3)
	Curiosity, innovation, originality, invention, promotion	
	Asking right questions	
	Placing limits	
	Considering non-engineering factors such as economic, commercial, political factors	Relating to economic and managerial aspects of the project beyond the operational/engineering areas presented in it; awareness of non-engineering considerations such as business and economic considerations, welfare considerations, business advantages, feasibility analyses, etc.; taking political and organizational considerations into account while providing a solution to the problem being examined in the final project (Questions 6, 25, 26)
Capabilities	Ability to carry out an analysis of requirements	Capacity to understand the needs and demands of the client; capacity to analyze the customer's needs, requirements and preferences(Questions 18, 19)
	Abstract thinking and the ability to develop the solution	Capacity to find a solution to a problem by "bypassing" the problem (Question 11)
	Functional analysis	
	"Seeing the future," vision of the future	
	Use of simulation and engineering tools	
	Optimization	The ability to apply cost-effective considerations (Question 23)
	Resolving systems failures and problems	
	Ability to offer several solutions to a problem	

From Table 14, we see that the questionnaire reflects only some of the components of the different engineering systems thinking aspects when several items sometimes reflect another theoretical component. From here, we can deduce that in order to examine the capacity for engineering systems thinking among pupils/students, the existing questionnaire must be expanded and items added to it that reflect all components of engineering systems thinking aspects. In addition, some of the elements reflecting an identical theoretical component of an aspect could be removed (such as Questions 6, 25, 26, which all deal with non-engineering factor considerations, such as economic and business considerations – one of these three questions may be removed, thereby reducing the number of questionnaire items).

In an analysis made using AMOS software, it was found that most of the elements in the questionnaire that have the individual traits aspect are explained well by this aspect, both in the pre- and post-questionnaires (these items are: Question 12 – future desire to be involved in a management discipline as team head, project manager or area manager; Question 21 – future preference to participate in management and to incorporate different interdisciplinary engineering areas; Question 27 – desire and preference to lead a team in carrying out a task).

From here, we can deduce that with respect to the individual traits aspect of the research subjects, their ultimate desire to integrate into the management discipline and lead a team of workers in carrying out a task, the final project did not serve as a source of change in regard to this tendency. Apparently, this preference, which already existed before starting work on the final projects, was maintained throughout the project's execution. In relating to the capabilities aspect, only Question 11 was clearly explained by this aspect in the pre- and post-questionnaires. This issue discussed the ability to find a solution to a problem by bypassing the problem. A surprising finding was that the issues dealing with the capacity to understand and analyze the needs, requirements, and preferences of a client (Questions 18, 19) did not have a high loading value for either questionnaire. In light of these findings, the capabilities aspect components, as expressed in the questionnaire items, should be revised.

The positive variance was found in the knowledge and cognitive characteristics aspect between the elements that were explained well by these items in the pre-questionnaire, compared to the items that were explained well by the same aspects in the post-questionnaires. The items explained well by the knowledge aspect in the post-questionnaire related to multidisciplinary knowledge, knowledge of project management and management models. It may be assumed that exposure to subjects in project management and the need for multidisciplinary knowledge in working on the final projects represents an explanation for this finding. The items explained well by the cognitive characteristics aspect in the post-questionnaire dealt with combinations and integrations between systems and processes, as well as economic and managerial aspects of the project. Here, too, we can assume that in carrying out the final project, learners were exposed to the need to examine the problem under discussion from different aspects. This led them to integrate the various processes presented in the project, all of which may explain this finding. Moreover, this finding is in line with the PBL approach in which students ask questions, make predictions, collect and analyze data, use technology, and share different ideas (Krajcik, Czerniak and Berger, 1999).

In summary, in a discussion of the analysis of engineering systems thinking components, it may be said that, contrary to the aspects of individual traits and capabilities, which maintained stability between the pre- and post- questionnaires, carrying out the final project, as regards the knowledge and cognitive characteristics aspects, apparently caused a change, primarily with respect to acquiring multidisciplinary knowledge and project management knowledge (in the knowledge aspect), in dealing with combining systems/processes, and in relating to the economic and business aspects of the project (in the cognitive characteristics aspect). It is important to emphasize that the test of stability between the loading of items in the pre- and post-questionnaires using AMOS software does not compare the scores received for these elements in both questionnaires.

In comparing the scores of the research subjects regarding the different aspects in the pre-questionnaire to the scores in the post-questionnaire, we see that for all of the various aspects (individual traits, capabilities, knowledge, cognitive characteristics), a marked difference was observed between students and pupils. This finding confirms the finding also found in an analysis of the complete questionnaire without the division into systems thinking aspects. In addition, and similar to the conclusion from the full questionnaire, no significant difference was observed regarding the effect of time (the pre-questionnaire as opposed to the post-questionnaire) between the different groups of pupils (3-unit study level as opposed to 5-unit study level) in comparing the scores of the various systems thinking aspects. The variance between pupils' and students' capacity for engineering systems thinking versus a lack of variance between pupils studying at a 3-unit study level and pupils studying at a 5-unit study level was discussed in the Findings section – an analysis of the results of the questionnaire assessing the capacity for engineering systems thinking. An interesting finding on this subject was that in regard to the knowledge and cognitive characteristics aspects, there was an advantage to pupils studying at a 3-unit study level over pupils studying at a 5-unit study level, although this benefit was not significant. A possible explanation for this is that carrying out a final project strengthens the capacity of engineering systems thinking in the knowledge and cognitive characteristics aspects, mainly among pupils who tend to think less analytically and in an in-depth fashion (pupils studying at a 3-unit study level).This results from acquiring multidisciplinary knowledge and the integration required while carrying out the project.

6. Conclusions and Recommendations

The analysis of the research findings presented in this paper implies that the capstone project could favorably impact the overall capacity of engineering systems thinking at an organizational level. In this analysis, the organization is seen as a system, which is studied using appropriate tools and models. Systems thinking enables capturing the essence of the system without detailed analysis of its constituent's components. In particular, systems thinking frees the observer from the need to fully understand marketing and other business management aspects that aim at promoting and improving the day to day operation of the organization. Through the capstone project, the student is required to relate the various disciplines that emerged in the project, and use statistical, engineering, and operational research tools, in their implementation. Furthermore, the student is required to integrate several areas involving, for example, quantitative estimation of cost and efficiency, various organizational processes and procedures, functional analysis of the organization, and marketing survey. All of these requirements contribute to developing methodology for engineering systems thinking capacity.

This research confirms that the capacity for engineering systems thinking is both an inherent trait as well as an acquired skill. That skill can be developed through multidisciplinary and interdisciplinary projects as well as integrative studies. It is recommended that projects be an integral part of the curriculum. We observed in this research that the experience gained by students who participated in the capstone projects had major impact in developing their capacity for engineering systems thinking. To a lesser extent, similar observation can be attributed to high school students who participated in the project.

The systems thinking engineering approach is crucial when dealing with large scale complex projects. It amounts to the preference of the macroscopic, rather than the microscopic, view of the system. Engineers involved with project development, who have a strong capacity for engineering systems thinking, perform better in developing an efficient conceptual approach to implementation of the project, they have better understanding of various needs and requirements of customers, and they are more successful in using simulations, optimization, and market surveys that could lead to useful alternative solutions. Systems thinking is helpful decision-making processes at all levels, up to the strategic level of an organization. Engineers and project managers with good systems thinking are capable of successfully managing tasks and projects involving multiple organizations using their ability to see the big picture without being distracted by small details.

This research study thus demonstrates that systems thinking can be evolved and improved by increased experience gathered in execution of multidisciplinary projects. Since systems thinking is a talent as well as a skill, an organization interested in training employees requiring the capacity for systems thinking should identify suitable individuals and engage them in broad responsibilities, diverse experiences, involvement in multidisciplinary projects, and on-the-job learning through joint work with employees that have a proven record for systems thinking.

The limitations of this study are the small sample size and a relatively small variety of participants. In order to further strengthen current study finding, it is necessary to carry out additional studies, including various groups of student, engineers and managers, all of whom involve in multidisciplinary projects.

To increase the validity of the study findings, other evaluation tools must be used, such as supervisor evaluation, colleague evaluation and some qualitative tools.

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