# Determinants of Systems Thinking in College Engineering Students: Research Initiation

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**Abstract**

As the world becomes increasingly complicated, systems thinking continues to gain recognition as an important and necessary skill for future engineers. Systems thinking does not replace traditional technical skills required of engineers; rather, it provides a complementary skillset to help better navigate complex systems and their corresponding problems. The increasing complexity of U.S. industries demands that universities train and educate future engineers with systems-thinking skills to solve the range of interconnected problems companies may face. Many factors have the potentials to impact systems-thinking skills. This paper aims to identify the effects of potential impacting factors on the systems-thinking skillset. Current college engineering students were the target population of the study. Structural Equation Modeling was performed to quantify the relationship between systems-thinking skills and potential impacting factors. The results of this study indicated that employment status would affect the overall systems-thinking skills of the engineering students and the engineering students with outside job experience will score higher than students without outside job experience in the systems-thinking skills.

***Keywords***: systems thinking skills, engineering education, complex systems problem-solving, impacting factors.

## Introduction

The world around us is constantly moving, changing to accommodate for systems that are considered better or improved. Complex system problems are those marked as having increasing complexity, excessive information, ambiguity, emergence and high levels of uncertainty. Dealing with problems exhibiting these characteristics requires non-technological, inherently social, organizational, and political knowledge [1], [2]. In response to effective problem-solving in the domain of complex systems, systems thinking evolved to include a wide variety of accepted approaches and techniques. Checkland [3] described systems thinking as the thought process which demonstrates the ability to think and speak in a new holistic language in order to understand and deal with complex systems problems. With this new discipline, identifying potential factors that affect systems thinking is important in establishing more effective ways to educate students to increase the workforce's effectiveness in dealing with complex systems problems. Exposing the factors that are significant toward providing students' foundation of systems thinking will better serve students' future in the industrial, academic, healthcare, military, and other sectors [4], [5]. However, to the best of our knowledge, there is no prior study explored the factors that affect systems thinking in college-age students. This study aims to close this gap and investigate what factors potentially lead to higher systems-thinking skills in college students, specifically engineering students. The potential factors assessed in this study will include gender, level of education, internship/cooperative participation, employment status, and grade point average (GPA).

## Systems-Thinking Skills and Impacting Factors

Prior studies assessed an individual's systems thinking using different systems thinking characteristics and measurements within education domain. For example, Hopper and Stave [6] developed ways to assess the effectiveness of systems thinking interventions in the field of education by defining systems thinking, determining what systems thinking interventions were being used in the current education models, and describing how the effects of interventions have been measured. Their definition uses the learning objectives in Bloom et al.'s [7] taxonomy to create their own proposed taxonomy as it pertains to systems thinking. Hopper and Stave's [6] taxonomy consisted of different measures including "recognizing interconnections, identifying feedback, understanding dynamic behavior, differentiating types of variables and flows, using conceptual models, creating simulation models, and testing policies (p. 17)." Sweeny and Sterman [8] developed a list of systems thinking characteristics to evaluate students' capability to understand the dynamic behavior of the complex problem. These characteristics included "understand how the behavior of a system arises from the interaction of its agents over time (i.e., dynamic complexity), discover and represent feedback processes (both positive and negative) hypothesized to underlie observed patterns of system behavior, identify stock and flow relationships, recognize delays and understand their impact, identify nonlinearities, and recognize and challenge the boundaries of mental (and formal) models (p. 250)." Resnick [9] verified the decentralized thinking capability among young students using 'programmable bricks'—"a tiny, portable computer embedded inside a LEGO® brick." Assaraf and Orion [10] examined the system thinking among the junior high school level students in the context of earth system education. Frank [5] tested the cognitive aptitude and systems thinking of a group of engineers by an instrument called 'capacity for engineering systems thinking.'

Previous studies have been conducted to explore how various factors affect college-aged students in different capacities. These factors measured were higher-order thinking, academic success, and academic performance. Prayoonsri et al. [11] found that classroom environment, psychological characteristics, intellectual characteristics, and family characteristics affect the higher-order thinking of students. Yigermal [12] showed that gender differences, the university entrance exam, and hours spent studying affecting the academic performance of undergraduate students. Okudan and Mohammed [13] and Oland et al. [14] showed that the student's gender and race were influencing factors in students' success. Weiser and Riggio [15] mentioned the potential correlation between a student's GPA and academic success. No study has concentrated on testing the impact of potential factors on the students' systems-thinking skills in dealing with complex systems problems. This research aims to evaluate which of these previously studied factors benefit or suppress the students' systems thinking ability to deal with multifaceted structures.

## Methods

Based on the literature review [11] – [15], all above-mentioned factors were found to potentially influence students' academic success and performance. Therefore, five impacting factors (gender, education classification, internship experience, outside work, and GPA) were measured to determine their impact on systems-thinking skills. The gender option included male, female, or other. The students' education classification included freshmen, sophomores, juniors, seniors, and graduate students. The students' participation in an internship or cooperative education experience was a yes/no option with outside work (i.e., co-ops or internships) excluded but including any paid work to complete a task or tasks while attending school. Employment status is the generalized term to indicate whether a student was employed. GPA describes students' academic achievement over their time at a particular institution or institutions. Jaradat's [1], [2] Systems-Thinking Skills instrument was used to gauge how an individual deals with complex problems. The instrument measures how holistically an individual handles complex problems and gives a score by analyzing seven major dimensions of systems thinking, for more detail about how the instrument was developed and how it works refer to [1], [2], [16], [17]).

Systems-thinking skills were measured using an online survey. The first part of the survey asked five questions about students' gender information, education level, internship/co-op opportunities, employment status, and grade point average. The second part of the survey used Jaradat's [1], [2] Systems Thinking-Skills instrument (39 questions). The questions factor into seven factors, including Complexity, Integration, Interconnectivity, Tolerant of Change, Emergence, holism and flexibility (see Table 1).

Table 1. Seven dimensions of Systems-Thinking Skills instrument [2]

| Less Systemic (Reductionist) | Dimension | More Systemic (Holistic) |
|---|---|---|
| **Simplicity (S)**: Avoid uncertainty, work on linear problems, prefer best solution, and prefer small-scale problems. | ***Level of Complexity***: Comfort with multidimensional problems and limited system understanding. | **Complexity (C)**: Expect uncertainty, work on multidimensional problems, prefer a working solution, and explore the surrounding environment. |
| **Autonomy (A)**: Preserve local autonomy, trend more toward independent decision and local performance level. | ***Level of Integration***: Balance between local level autonomy versus system integration. | **Integration (G)**: Preserve global integration, trend more toward dependent decisions and global performance. |
| **Isolation (N)**: Inclined to local interaction, follow detailed plan, prefer to work individually, enjoy working in small systems, and interested more in cause-effect solution. | ***Level of Interaction***: Interconnectedness in coordination and communication among multiple systems. | **Interconnectivity (I)**: Inclined to global interactions, follow general plan, work within a team, and interested less in identifiable cause-effect relationships |
| **Resistance to Change (V)**: Prefer taking few perspectives into consideration, over specify requirements, focus more on internal forces, like short-range plans, tend to settle things, and work best in a stable environment. | ***Level of Change***: Comfort with rapidly shifting systems and situations. | **Tolerant of Change (Y)**: Prefer taking multiple perspectives into consideration, underspecify requirements, focus more on external forces, like long-range plans, keep options open, and work best in a changing environment. |
| **Stability (T)**: Prepare detailed plans beforehand, focus on the details, uncomfortable with uncertainty, believe work environment is under control, and enjoy objectivity and technical problems. | ***Level of Uncertainty***: Acceptance of unpredictable situations with limited control. | **Emergence (E)**: React to situations as they occur, focus on the whole, comfortable with uncertainty, believe work environment is difficult to control, and enjoy subjectivity and non-technical problems. |
| **Reductionism (R)**: Focus on particulars and prefer analyzing the parts for better performance. | ***Systems Worldview***: Understanding system behavior at the whole versus part level. | **Holism (H)**: Focus on the whole, interested more in the big picture, and interested in concepts and abstract meaning of ideas. |
| **Rigidity (D)**: Prefer not to change, like determined plans, not open to new ideas, and motivated by routine. | ***Level of Flexibility***: Accommodation of change or modifications in systems or approach. | **Flexibility (F)**: Accommodating to change, like flexible plan, open to new ideas, and unmotivated by routine. |

We hypothesized each of the five impacting factors (gender, education classification, internship experience, outside work, and GPA) would affect students' systems-thinking skills and list the hypotheses below:

$\boldsymbol{H_1}$: *There is a significant relationship between engineering students' impacting factors, including gender ($\boldsymbol{H_a}$), education level ($\boldsymbol{H_b}$), internship/co-op status ($\boldsymbol{H_c}$), employment status ($\boldsymbol{H_d}$), and GPA ($\boldsymbol{H_e}$) and their systems-thinking skills.*

Figure 1 represents the logic flow of this study. The latent variable is oval, while the observed variables are rectangles and the error terms are circles. Seven dimensions of systems thinking loaded on the latent variable (called *Systems-Thinking skills*) which serves as the latent dependent variable of the study. The proposed theoretical model investigated the potential relationship between impacting factors and engineering students' systems-thinking skills.

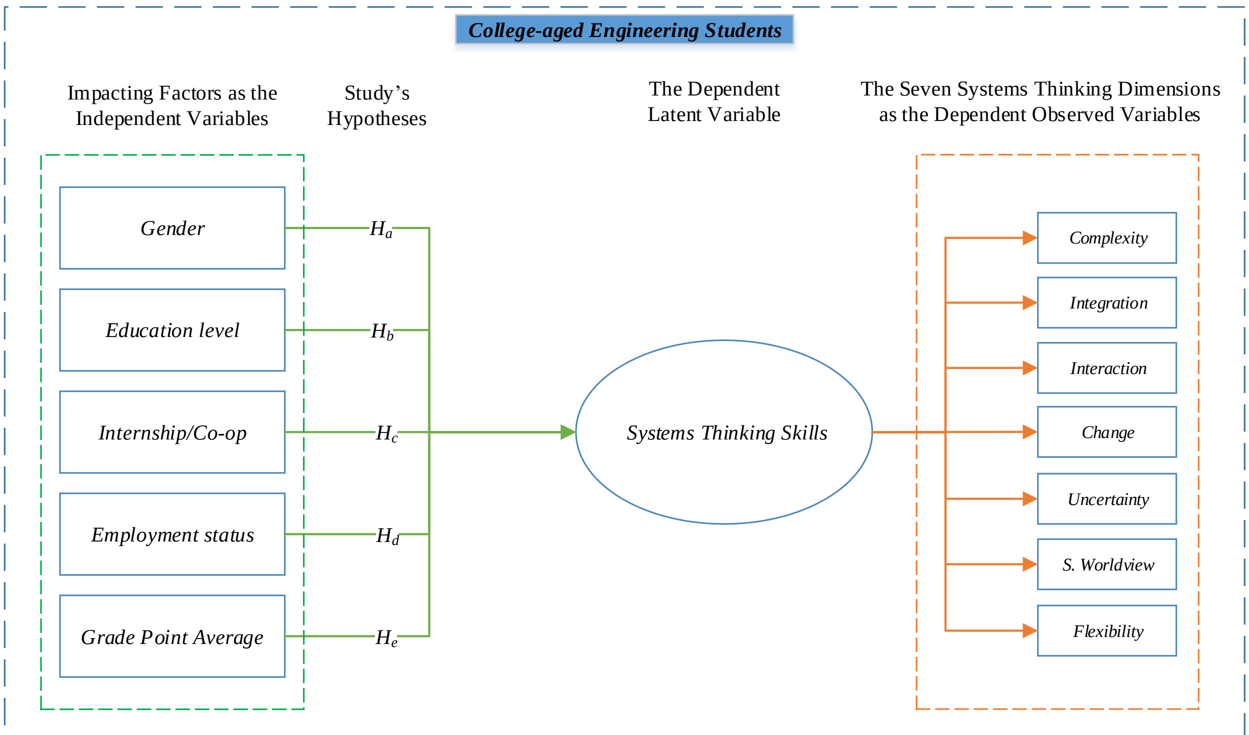



Figure 1. The Proposed Theoretical Model

## Results and Discussion

Table 2 shows the descriptive statistics of the 50 engineering students that participated in the study. The participants were informed that their participation was entirely voluntary and anonymous.

Table 2: The descriptive statistics of the study sample (independent variables)

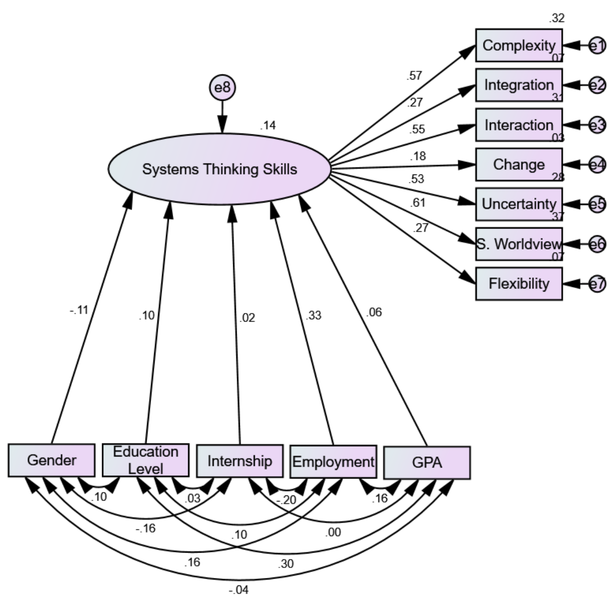
| Demographic | | Category | | | | |
|---|---|---|---|---|---|---|
| **1** | **Gender** | Female | Male | | | |
| | | 24 | 26 | | | |
| **2** | **Education level** | Freshman | Sophomore | Junior | Senior | Graduate |
| | | 0 | 0 | 9 | 27 | 14 |
| **3** | **Internship/Co-Op** | Yes | No | | | |
| | | 25 | 25 | | | |
| **4** | **Employment Status** | Yes | No | | | |
| | | 23 | 27 | | | |
| **5** | **GPA** | Below 2.00 | 2.00-2.50 | 2.51-3.00 | 3.01-3.50 | 3.51-4.00 |
| | | 1 | 1 | 15 | 13 | 20 |

The overall systems-thinking score was calculated by the average score of seven systems-thinking scores for each individual; then, the average and standard deviation of individuals overall ST scores within each demographic category were measured and presented in Table 3.

Table 3. Summary statistics for Overall ST Score (out of 100 points)

| **Variable** | **Gender** | | **Education Level** | | | **Internship/Co-op participation** | | **Employment status** | | **GPA** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Level** | Female | Male | Junior | Senior | Graduate | Yes | No | Yes | No | 2.51-3.00 | 3.01-3.50 | 3.51-4.00 |
| ***Overall Systems-Thinking Score*** | 51.1 (14.6) | 50.9 (12.1) | 48.6 (10.0) | 50.1 (10.8) | 54.1 (18.7) | 50.2 (11.2) | 51.8 (15.2) | **54.9 (13.8)** | **47.2 (11.1)** | 50.3 (11.4) | 48.5 (10.0) | 52.9 (16.5) |

The structural equation modeling results are summarized in Figure 2 (standardized solution) and Table 4 in the form of a full structural model which presents the relationship among all evaluated factors. AMOS version 24.0 was used to run the structural equation modeling (SEM). The seven dimensions of systems thinking loaded on the latent variable (called Systems-Thinking skills) which serves as the latent dependent variable of the study. Five factors served as the study's independent variables. Among all five independent factors, only the student's employment status had a significant relationship (standardized regression weight of .33 at 90% confidence interval) with the level of systems-thinking skills; consequently, $\boldsymbol{H_d}$ *(employment status)* was supported; and $\boldsymbol{H_a}$ *(gender)*, $\boldsymbol{H_b}$ *(education level)*, $\boldsymbol{H_c}$ *(internship/co-op status), and* $\boldsymbol{H_e}$ *(GPA)* were not supported.




*Chi-squre/DF = 1.134; P(chi-squre) = .332; GFI = .928; RMSEA = .052*

Figure 2. The Full Structural Analysis of the Proposed Theoretical Model

Table 4. The result of SEM hypothesis testing

| Independent Variable | Corresponding Hypothesis | Regression Weights | | *t*-value | Sig. | Result Supported |
|---|---|---|---|---|---|---|
| | | Unstandardized estimate (Std. Error) | Standardized estimate | | | |
| ***Gender*** | $\boldsymbol{H_a}$ | -3.09 (4.66) | -0.11 | -0.663 | 0.508 | No |
| ***Education level*** | $\boldsymbol{H_b}$ | 2.02 (3.55) | 0.10 | 0.568 | 0.570 | No |
| ***Internship/Co-Op*** | $\boldsymbol{H_c}$ | 0.54 (4.60) | 0.02 | 0.117 | 0.907 | No |
| ***Employment Status*** | $\boldsymbol{H_d}$ | **8.86 (5.18)** | **0.33** | **1.711** | **0.087** | **Yes** |
| ***GPA*** | $\boldsymbol{H_e}$ | 0.88 (2.43) | 0.06 | 0.363 | 0.716 | No |

Gender did not significantly impact students' systems-thinking skills; $\boldsymbol{H_a}$ was not supported. No significance was found in the internship/co-op category (e.g. $\boldsymbol{H_c}$ was not supported). Grade Point Average was not found to be significant in the study (e.g. $\boldsymbol{H_e}$ was not supported). No significance was found in the education-level category (e.g. $\boldsymbol{H_b}$ was not supported). However, because of the low sample size and subsequent low power of the current study, it cannot be concluded that engineering students in different education levels (e.g. senior, junior, and graduate) are not significantly different regarding their systems-thinking skills. Data associated with small sample sizes (e.g. less than 100) is more likely to be non-normal than the large sample size's data (e.g. more than 300) [18, pp. 116-117]. As a result, the regression weights and significance level in this study might be impacted by the non-normal (noisy) data associated with the small sample size [19].

Systems thinking was significantly predicted by student employment status. The impact of employment status on students' systems-thinking skills was significant at 90% confidence interval ($\alpha < .10$) with standardized regression weight of .33 (e.g. $\boldsymbol{H_d}$ was supported). The lower significance (i.e., $\alpha < .10$ instead of $\alpha < .05$) and low regression weight in the current study might be because of the small sample size (e.g. 50). If a student had a job outside of school, they tended to be more holistic-thinking than their counterparts who are not employed outside of school. Employed engineering students had higher systemic skills scores in five out of seven ST dimensions (i.e., *complexity*, *integration*, *uncertainty*, *systems worldview*, and *flexibility*). Having a job outside of school might be one way to prepare students to be more equipped with complex multi-task ability and to work more effectively and efficiently in their future career.

## Conclusion and Future Research

This study was conducted to analyze the determinant(s) that may or may not affect the ability of an engineering student to be a more or less holistic-thinker. The results found that only one determinant analyzed, employment status, had a significant effect on students' systems-thinking. Students who had a job outside of school tended to be more likely to have higher systems thinking skills than students who did not have a job outside of school. The main takeaways can be seen in the bullet points below:

- Engineering students with outside employment scored higher in overall systems-thinking skills than students without a job outside of school.
- Gender, grade point average, level of education, internship/co-op did not affect the development of students' systems-thinking skills significantly.

This study was limited in a variety of ways. The most pressing concern was the limited sample size that was used to gather and determine results. In the future, more emphasis should be placed on gathering a large sample size to obtain more accurate results. The main ways to improve this study can be seen in the bullet points below:

- Involving the larger sample size participants to have the more reliable results
- Testing whether outside work should be categorized by the number of hours the individual works could be further evaluated.
- Involving more engineering students at differing universities to validate the results.
- Research could delve into how other extra-curricular activities besides having a job might affect a student's systems thinking ability. These extra-curricular activities could include, but are not limited to: playing a sport, being involved in an organization (e.g. student government), and volunteering.

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