Students' Systems Thinking Competency Level Detection through Software Cost Estimation Concept Modeling

J.R. Aguilar-Cisneros[1], R. Valerdi[2], B. P. Sullivan[3]
[1] UPAEP, Department of Engineering, Puebla, Pue., México
e-mail: jorge.aguilar@upaep.mx ORCID: 0000-0003-3040-157X
[2]University of Arizona, Department of Systems and Industrial Engineering, Tucson, AZ., USA
e-mail: rvalerdi@arizona.edu ORCID: 0000-0002-2746-0395
[3] University of Twente, Department of Design, Production and Management, Enschede, the Netherlands
e-mail: b.p.sullivan@utwente.nl ORCID: 0000-0002-4646-7277
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Abstract—Systems Thinking Competencies have become extremely important and widely studied due to increasing complexity of technical and societal systems. Because of this, when they are taught, it is extremely useful to identify whether or not students demonstrate Systems Thinking Competencies so that effective teaching strategies can be designed. Through the use of the Adapted Holistic Scoring Method we seek to assess Concept Maps developed by postgraduate and undergraduate engineering students in order to determine their knowledge of Systems Thinking Competencies. Firstly, their background in cost estimation drivers was identified, and secondly, their Systems Thinking Competence proficiency level. We assessed how a short cost estimation training improved specific Systems Thinking Competencies. This research contributes to the body of knowledge because it provides empirical evidence on systems thinking competencies among engineering students in the context of cost estimation. The research was organized in two phases. First, Students demonstrated knowledge of cost estimation drivers, and were asked about specific levels of Systems Thinking Competencies. Second, after students were taught systems thinking competencies, their knowledge of the connection between cost drivers and Systems Thinking Competencies was obtained. A Mann-Whitney U-test was applied in order to identify if there were significant differences between Phase 1 and Phase 2 in both Estimation Cost Drivers included and Systems Thinking Competence Level Demonstrated Results show improvement in a specific Systems Thinking competency – ability to see relationships – among the student population studied (N = 45).

D**OI**:

1. INTRODUCTION

Systems Thinking is a holistic approach to analyze, and solve complex problems and systems [56], [51]. It means looking for an acceptable solution among several potential solutions. These solutions will be highly correlated, while others may have a cause and effect relationship. Systems Thinking emphasizes the complexity of relationships, seeking out webs of causality rather than single, linear causes [1]. In this regard, this study focuses on, firstly, identifying how students' thinking evolves over time about cost estimation drivers while they learn about the topic. Secondly, we focus on how students represent their mental models through a concept map and how those Concept Maps shed light on Systems Thinking competencies. Particularly, one Systems Thinking Competence defined by [49], was analyzed. The study was applied to undergraduate and postgraduate students. They were enrolled in a cost estimation course during the spring 2020, where, among several concepts, cost estimation drivers were studied. Cost estimation drivers are relevant when effort to build a project has to be determined. Additionally, there are different models or methodologies regarding estimating. However, this paper took into account the Constructive

Cost Model (COCOMO) for software cost estimation [6].

Concept Maps were analyzed and assessed in order to determine whether a specific Systems Thinking Competence was embedded into students' mental models. Particularly, we assessed students' ability to apply Systems Thinking Competence #3 (STC #3): "Ability to see relationships" which is defined as "a system can be understood in the context of relationships" [49].

The term competency/competence has multiple interpretations. This ranges from a description of competency/competence in terms of performance, and skills acquired by training to a broad overarching view that encompasses knowledge, understanding, skills, and attitudes [23]. Sometimes competency and competence are used as synonyms. We use the term competence which is defined as a set of knowledge, skills, and experiences acquired through training or teaching. Competencies are necessary to effectively carry out a defined function, service, or solve different kinds of problems. Mainly, complex problems.

After Students' Concept Maps (SCMs) were assessed in phase 2, the outcomes showed an increased knowledge on software cost estimation drivers compared to student knowledge demonstrated during phase 1. Additionally, students demonstrated a higher level of competence for Systems Thinking Competence #3: Ability to see relationships in phase 2 compared to phase 1. A complete description of these outcomes are provided in sections below.

2. BACKGROUND

The term Systems Thinking is known as "the art and science of making reliable inferences about behavior by developing an increasingly deep understanding of an underlying structure" [37]. This early definition built upon the notion of a system by considering the interconnections between elements or parts of a system in order to coherently organize and conceptualize a complex entity in a systematic manner according to characteristics/behaviors, and their function or purpose [42], [27]. Systems Thinking has been applied in a wide number of areas, for example [28] used Systems Thinking to show the power of quality function deployment in profitability engagement and profit generation. [19] states Systems Thinking can be used as an organizational learning tool that incorporates causal loop diagrams, based on the needs of new ventures and micro business. Systems Thinking was shown to be incorporated in action research interventions to successfully implement organizational change and increase collaboration throughout the development effort [40]. Based on these studies, Systems Thinking has been used as a tool for managing the complexity of systems, technical and societal, by considering the future implications of decision making and their long-term consequences. Additionally, Systems Thinking can be applied to decision making as it often involves understanding the complexity of the situation, to see causal relationships, identify dynamic relationships among variables, and so on. In order to identify relationships [29], [41], and complex relationships [13], [20], Conceptual Maps are often used for representing an individuals' understanding of the problem.

2.1. *Systems Thinking Competencies and Skills*

There is disagreement in the literature about systems thinking competencies definition and their interpretation in different contexts. The interpretation ranges from a description of a competency in terms of performance and skills acquired by training to a broad view that encompasses knowledge, understanding, skills, abilities and attitudes [23]. The ECT [18] defines competence as: "Competence means the proven ability to use knowledge, skills and personal, social and/or methodological abilities, in work or study situations and in professional and personal development". As previously mentioned, this paper uses the term competence which is defined as a set of skills acquired by training or teaching. Systems Thinking can be described as a dual ability to understand systems and analyze circumstances, questions, or problems from a systems perspective [11]. Systems can be divided into three aspects, function (utility), structure (form) and behavior (dynamics) [24]. When both terms, Competence and Systems

Thinking, are put together, Systems Thinking Competence (STC) arises. STC can be defined as: "Aspect that implies skills, knowledge, attitudes and behavior applied to tasks or activities where Systems Thinking perspective is needed". The following characteristics (competencies) of Systems Thinking are helpful to this discussion [8]: #1: The ability to identify the components of a system and process within the system. #2: The ability to identify relationships among the system's components. #3: The ability to identify dynamic relationships within the system, and so on. The characteristic #1 has been identified by different authors, among them [5], [21]. With respect to the characteristic #2, it was also defined by [15] and [50]. [56] stated that Systems Thinking can help develop higher-order thinking skills, such as critical thinking, in order to understand and address complex, interdisciplinary, real-world problems. Similarly, critical thinking skills (competencies) were defined by [38]: #1: Dynamic Thinking - the ability to see and deduce behavior patterns. #2: Closed-Loop Thinking - Thinking in terms of closed loops, the world is seen as a set of interdependent processes rather than a one-way relationship. #3: Generic Thinking - To think in a generic way instead of a specific way. #4: Structural Thinking - Thinking has to be in terms of units of measure. #5: Operational Thinking - thinking in terms of how things really work –not how they theoretically work. #6: Continuum thinking - It is nourished primarily by working with simulation models. #7: Scientific Thinking - being rigorous about testing hypotheses.

There are a considerable number of Systems Thinking Competencies that have been identified by a large number of authors [21], [17], [2], [3]. Systems Thinking Competencies can be learned through training. Among all these competencies, this paper was focused on one of the eight STC defined by [49]. The competence selected, among eight of them, was # 3 because it was most appropriate for surfacing student understanding of the complexities of cost models. For completeness, all of them are listed: #1: Ability to define the universe appropriately.- Systems Thinking is a process of identifying, estimating or inferring how general aspects influence the universe. #2: Ability to define the overall system appropriately, defining the right boundaries.- It means viewing problems as parts of an overall system. **Competence #3: Ability to see relationships, a system can be understood in the context of relationships**. #4: Ability to see things holistically, avoiding a reductionism analysis. #5: Ability to understand complexity, events separated by distance and time can cause large changes in complex systems. #6: Ability to communicate across disciplines, Systems Thinking promotes communication at all levels. #7: Ability to take advantage of a broad range of concepts, principles, models, methods and tools, any kind of system may be studied. #8: Metacognition – the ability to think about thinking.

The competence #3 (STC #3) was selected because this competence is most closely related to cost modeling and allows to isolate a single competence without worrying about the confounding or mediating effects of others.

2.2. *Software Cost Estimation Models*

There are several Software Cost Estimation Models, among them, COSMIC [53], User Stories [54], and COCOMO all of which estimate the amount of effort in person-months (PM). COCOMO's cost estimating relationship includes effort multipliers (EM), scale factors, and cost drivers as inputs that represent the complexity of the software product for which effort is being estimated. COCOMO defines five Scale Factors: Precedentedness (PREC), Development Flexibility (FLEX), Architecture/ Risk Resolution (RESL), Team Cohesion (TEAM), Process Maturity (PMAT). Additionally, COCOMO defines seventeen Effort Multipliers and cost drivers which are organized into four groups: Product Factors, Platform Factors, Personnel Factors, and Project Factors. Product factors include: Software Reliability (RELY), Database Size (DATA), Product complexity (CPLX), Developed for Reusability (RUSE), and Documentation match to life cycle needs (DOCU). Platform Factors include: Execution Time Constraint (TIME), Main Storage Constraint (STOR), Platform

Volatility (PVOL). Personnel Factors include: Analyst Capability (ACAP), Programmer Capability (PCAP), Personnel Continuity (PCON), Applications Experience (APEX), Language and Tool Experience (LTEX), Platform Experience (PLEX) and, Project Factors include: Use of Software Tools (TOOL), Multisite Development (SITE), Required Development Schedule (SCED). These Cost Drivers were taught to the student population who participated in this research (Phase 1) and were subsequently evaluated in their concept maps (Phase 2).

Effort Multipliers and Scale Factors were identified in each Student's Concept Map in order to determine how many of them utilized them in their own concept map. Based on this result, a usage rate was assigned to each SxCM [45].

2.3. *Scoring of Student Concept Maps*

Concept Maps were developed by [33] at Cornell University, in order to understand changes in students' knowledge, because CMs are graphical tools for organizing and representing conceptual understanding [46]. Additionally, CMs and Systems Thinking can be used together because they share common characteristics such as structure, dynamism and hierarchy. Researchers indicate that an increase in the number of concepts, connections and diversity in CMs are a reliable measures of students' systematic thinking. [55], [43] Furthermore, CMs can be used to encourage student thinking according to The National Science Education Standards [31]. CMs have been used in a wide spectrum of areas due to their advantages, for instance, [48] used CMs to assess course level of students' statistical knowledge and to evaluate the learning of specific terminology and the interconnections among those terms. [32] point out that one of the greatest attributes of CMs is its power to reveal the structure, organization, and elaboration of understanding. [44], [39], mentioned CMs are an effective way to organize material and identify knowledge gaps in a learner's cognitive structure. [12] used CMs in a sophomore multidisciplinary engineering course to identify fundamental engineering concepts and then to map the relationships among several engineering areas.

However, it is important to highlight some CMs disadvantages. First, it could be possible that students don't have experience with mapping modeling, or skills to develop CMs [14]. Second, low-directed tasks such as the case of no conditions and list of concepts can affect the quality of developing CMs [10]. Despite these disadvantages, using CMs to assess students' knowledge can be useful. It represents a challenge when data generated has to be analyzed [35], mainly because there is no specific set of rules to transform qualitative analysis data into findings. Despite that, some map scoring methods [52] have been developed.

Researchers [52] have identified three scoring types of methods: Traditional, Holistic, and Categorical. The traditional method evaluates CMs by individual elements. Holistic method evaluates CMs as a whole and focuses on attributes of the entire map, and categorical method bases its scoring CMs on predetermined conceptual categories.

Additionally, there are some tools for Systems Thinking assessment. For instance, in STEM education, tools have been divided into three types [56]: assessment rubrics, consisting of classification and scoring guidelines, multiple-choice questionnaires, consisting of closed-ended questions, and written responses and interviews, consisting of coding schemes. Furthermore, [7] identified different levels of concepts and sub concepts within a Concept Map which involved a point system based on the map's hierarchical levels. One point was given for each first level branch, two for each second level branch, three for each third level, and so on. Additionally, one point was given for each hierarchical level. The total score for the map was the sum of these points. Other authors [48] suggest reviewing which concepts were identified by participants within the maps and how often. [30] believe that when scoring a map, the focus should be on map quality instead of the quality of concepts. Other authors [26] identified two elements to grade a CM: the mapping task and the evaluation. The first element represents the student's knowledge and the second involves an examination of content and structure of the CM. Additionally, [26] did an evaluation of six scoring methods: 1) holistic, 2) holistic with master map, 3) relational, 4) relational with master map, 5) structural, and 6) structural with master map. To calculate similarity between subjects' Concept Maps, and the Master Concept Map (MCM), [26] a set of theoretical methods described by [16] can be used. The first step consists in establishing the set of related concepts for each neighborhood; a neighborhood is defined for each concept represented on the maps. Then, for each neighborhood, a similarity is calculated by dividing the intersection of the neighborhood sets for the two maps by their union. Finally, the mean of the neighborhood similarities is calculated. [46] examined the effectiveness of Concept Maps as an assessment tool for students' Systems Thinking. They used a model named Systems Thinking Hierarchy, where eight hierarchical entities were categorized. Additional research analyzed teachers' Systems Thinking skills through Concept Maps and questionnaires [4].

In summary, there is a large quantity of research where Concept Maps have been used in order to identify Systems Thinking skills or competencies [47], [36], [34], [25], [22]. These studies have covered a broad range of areas such as healthcare, biology, chemistry, and civil engineering across multiple academic levels such as High School, undergraduate, and graduate. Despite considerable research being developed, it is important to apply concept maps to additional studies in order to improve the methodology as we gain insights about its applicability.

3. RESEARCH METHODOLOGY

This section describes the research methodologies' main elements and instruments used to gather and analyze data.

3.1. *Research Overview*

In [9] authors analyzed whether particular features (medium) of Concept Maps affect the assessment of student's Systems Thinking. They found that the medium rarely influenced the validity of Concept Maps for Systems Thinking. Furthermore, the authors suggest Concept Maps as an appropriate assessment of Systems Thinking.

However, for this research neither specific tool to build Concept Maps was requested nor specific instructions to build them was given to participating students. Additionally, for this study an Adapted Holistic Scoring Method (AHSM) was used together with a Master Map Methodology.

The original holistic methodology was adapted because of the type of raw data gathered.

Different scoring methodologies were considered such as, i) holistic, ii) holistic with master map, iii) relational, iv) relational with master map, v) structural, and vi) structural with master map. However, additional raw data would have been necessary in order to use relational or structural scoring methodology.

Relational scoring methodology was not used because there wasn't a request in order to identify relationships between cost drivers. Structural scoring methodology was not used because hierarchical levels were not requested when students developed their Concept Maps. In other words, neither relationships nor hierarchical levels were asked because the objective was to keep tasks as simple as possible. Students were given a simple task so that they could focus on developing their Concept Maps with total freedom and minimal directions.

There were two assessments of student concept maps. The first one was applied in January (Phase 1) and the second one in February (Phase 2), both of them in 2020. The assessments consisted identifying how many Software Cost Drivers students were able to use, and how many Scale Factors and Effort Multipliers they were able to specify in their Concept Maps, additionally the level of Systems Thinking Competence #3 embedded into their Concept Maps was examined. The second assessment analyzed whether students used specific software cost drivers. Particularly, the analysis looked for the use of PREC, FLEX, RESL, TEAM and PMAT scale factors. We also looked for the use of: RELY, DATA, CPLX,

RUSE, DOCU, TIME, STOR, PVOL, ACAP, PCAP, PCOM, APEX, PLEX, LTEX, TOOL, SITE, and SCED in student developed concept maps. In addition, the application of System Thinking Competence #3 into their Concept Maps was evaluated. Particularly, we analyzed the change of this competency between Phases 1 and 2.

3.2. *Research Problem*

Solving complex problems is one of the main activities in some industries, where, in the future, students could find themselves working in. In this sense, identifying Systems Thinking Competencies that students apply most naturally can be useful. With this goal, training activities to strengthen them could be designed and implemented. This research focused on one Systems Thinking Competence demonstrated by a group of students (graduate and undergrad) on a specific task.

3.3. *Research Focus*

This research was focused on determining whether students demonstrated a systems thinking competency, particularly we focused on how students change their ability to see relationships after learning about software cost estimation models and how they represent such relationships using a Concept Map. Applying the Adapted Holistic Scoring Method together with the assessment rubric, student Concept Maps were assessed.

3.4. *Research Aim and Research Questions*

The two research questions guiding this study are:

RQ1: How does ability to see relationships (STC #3) change over time as a result of learning cost modeling concepts?

RQ2: How do students' mental models of the factors that impact project costs change over time?

3.5. *Participants*

This research was applied to a sample of participants consisting of undergraduate and postgraduate students. All of them were enrolled at different Systems and Industrial Engineering Department majors. The first phase had 61 students participate and the second phase had 45 students. Despite the study was applied to the same group of students, the second assessment was taken for fewer students because this study was entirely optional. We only analyzed concept maps from students who participated in both phases (N = 45).

3.6. *Instrument and Procedures*

The study included two phases. In the first phase (see Figure. 1) we assessed the degree of similarity between Students' CMs (SxCM) and the Master Concept Map (MCM). High levels of similarity indicate SxCMs include a considerable number of Cost Estimation Drivers in their Concept Maps. Low levels of similarity indicate SxCMs included few Cost Estimation Drivers. In order to do this assessment, the Adapted Holistic Scoring Method [26] was used (See Figure 1). However, an adaptation was done. According to [26] in order to assess CMs similarity, these have to be constructed using the same set of concepts. However, when SxCMs were requested for this research, and when MCMs were developed, both of them used different sets of concepts because our students did not receive a common set of concepts. Mainly, because our students had complete freedom to build their SxCMs. For the same reason our students did not receive specific information about how to build CMs. During the first assessment, students were not familiar with Cost Estimation Drivers. In other words, students' self-knowledge about cost estimation drivers was assessed.

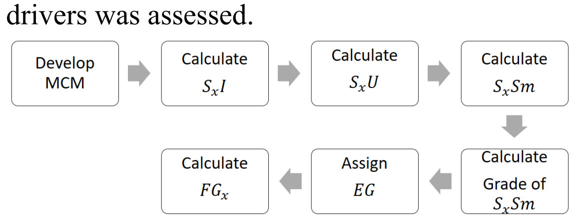

Fig. 1. Adapted Holistic Scoring Method (AHSM).

Equations (See Figure 2) were used in order to calculate: A) CMs Intersection (SxI), B) CMs Union (SxU), C) Similarity (SxSm) between

MCMs and SxCMs , D) Student's CMs Grade (Gx), E) Expert Grade (EG), and F) Final grade (FGx).

Concept Maps Intersection means to take the MCM (a map developed by an expert), and compare it with each CMs developed by students (SxCM). As a result, an Intersection (SxI) between both of them was determined. This intersection shows equal or equivalent elements between MCMs and SxCM. To calculate union, MCM cost estimation drivers plus SxCMs cost estimation drivers minus SxI elements, and as a result SxU was obtained. After this operation, similarity between SxI and SxU was calculated. To do this, SxI had to be divided by SxU, and as a result SxSm was obtained. To generate SxCM's grade, SxSm was multiplied by 10. As a result, the first SxCM's grade was obtained. Continuing with this process, an expert grade (EG) for each SxCMs was assigned. With the EG and the Gx the final grade was obtained. The final grade (FGx) was generated as an average between Gx and EG. Each SxCMs was examined by an expert, a grade (0 to 10) was assigned based on the rater's judgment.

$$A)\ S_xI = MCM \cap S_xCM$$

$$B)\ S_xU = \left(\sum_{i=1}^{n} MCM_{term_i} + \sum_{i=1}^{n} S_xCM\ term_i\right) - S_xI$$

$$C)\ S_xS_m = \frac{S_xI}{S_xU}$$

$$D)\ G_x = S_xS_m * 10$$

$$E) EG = ExperteGrade$$

$$F)\ FG_x = (EG + G_x)/2$$

Fig.2. Equations for Adapted Holistic Scoring Method

In phase 1 the Assessment Rubric to assess Level of Systems Thinking competence #3 reached by students was evaluated for each Concept Map.

3.7. *Assessment Rubric*

In Phase 1 and Phase 2, the third Systems Thinking competency (STC #3), "Ability to see relationships within the cost estimation project itself and between the cost estimation project and the universe" was assessed among student Concept Maps. The assessment was done through a rubric (see Table 1). This rubric was used to evaluate each SxCM, and the degree to which System Thinking Competency #3 (STC#3) was demonstrated in the student Concept Maps. The elements of STM#3 identified indicate whether students saw relationships between the cost estimation drivers (direct costs) and the costs around the project (indirect costs). Regarding relationships, three levels were defined: Low, Medium, and High. A SxCMs received a low score if 0 or 1 related element with STC #3 was identified, when 0 elements were identified, it means SxCMs only contains Cost Drivers Estimation related with the cost estimation project itself (direct costs). A SxCMs received a medium score if two related elements with STC #3 were identified. Finally, a SxCMs received a high score if three or more related elements with STC #3 were identified, in other words, if a student identified direct, and indirect costs, it implies student demonstrated the Systems Thinking Competency #3 because he or she was able to show relationships between the cost drivers estimation project and the universe.

Table 1. Rubric to assess SxCMs vs STC #3

SxCM	Assesment STC #3			Identified Level		
	Low	Medium	High	1	2	3
1	**Low.** If 1 or 0 external elements were identified	**Medium.** If 2 external elements were identified	**High.** If 3 or more external elements were identified			

The methodology to assess the STC #3 in each SxCMs is shown in Figure 3. First, they were assigned with a level: low, medium, or high depending on how many elements related with STC #3 identified in each Concept Map. When all SxCMs were evaluated, an analysis was applied in order to identify whether STC #3 was demonstrated or not. The results are described below and summarized in Figures 11 to 14.

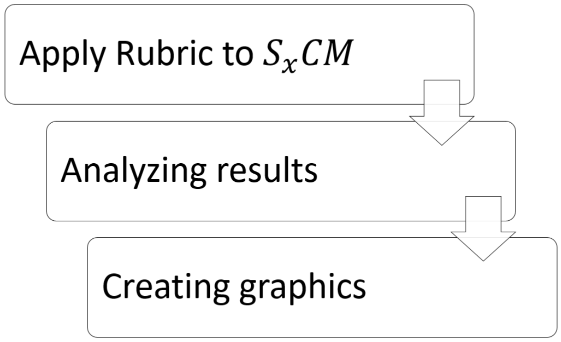

Fig.3. Methodology to identify STC #3 into SxCMs.

3.8. *Statistical Test*

The Mann-Whitney U-test was used to compare SxCMs developed in phase 1 vs SxCM developed in phase 2. At each phase, two different aspects were assessed. The first aspect focused on how many Cost Estimation Drivers students included in their Concept Maps. The second aspect focused on what level of STC #3 was demonstrated by students in their Concept Maps.

This statistical test was used to determine if there was a significant difference between the first and second phase regarding the Cost Estimation Drivers included, and if there was a significant difference between the first and second phase regarding the STC #3's level reached.

The first Mann-Whitney test was applied to Cost Estimation Drivers. The Null Hypothesis (H_0), and the alternative hypothesis(H_1) were defined.

$H_0 = NCED_1 >= NCED_2$

$H_1 = NCED_1 < NCED_2$

$NCED_1$ represents the number of Cost Estimation Drivers included by students in their CMs in the first phase study, and $NCED_2$ represents the number of Cost Estimation Drivers included by students in their CMs in the second phase study.

A confidence level of 95%, and a significance level of 0.05 ($\alpha = 0.05$) were used.

The size sample was 105, in the first phase study there were 60 students (one of them was eliminated) and in the second phase there were 45 students. It means, 105 Concept Maps were analyzed.

The second Mann-Whitney test was applied to Systems Thinking Competence Level #3 reached by students. The Null Hypothesis (H_0), and the alternative hypothesis(H_1) were defined.

$H_0 = STCL_1 <= STCL_2$

$H_1 = STCL_1 > STCL_2$

$STCL_1$ represents the level of Systems Thinking Competence #3 reached by students in their CMs in the first phase study, and $STCL_2$ represents the level of Systems Thinking Competence #3 demonstrated by students in their CMs in phase 2 of the study.

A confidence level of 95%, and a significance level of 0.05 ($\alpha = 0.05$) were used.

The size sample was 95. In the first phase study there were 54 students and in the second phase there were 41 students. Some students were eliminated because they didn't reach any level of STC#3.

Some parameters are, U and Z_u, as show in Figure 5.

$$U_1 = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1$$

$$U_2 = n_1 n_2 + \frac{n_2(n_2+1)}{2} - R_2$$

Fig. 4. Equations to compute U

$$Z_u = \frac{\left| U - \frac{n_1 n_2}{2} \right|}{\sqrt[2]{\frac{n_1 n_2 (n_1 + n_2 + 1)}{12}}}$$

Fig. 5. Equation to compute Z_u

4. RESULTS

The first section presents the outcomes regarding degree of similarity between Students' CMs (SxCM) and the Master CMs (MCM). Additionally, the results regarding the level of Systems Thinking Competence (STC #3) reached, "Ability to see relationships within the cost estimation project itself and between the cost estimation project and the universe" are shown.

The second section presents the results of the Mann-Whitney statistical test applied in order to identify whether or not changes between Phase 1 and Phase 2 were statistically significant.

4.1. Adaptive Holistic Scoring Method and R*ubric Results*

The first assessment (phase one), maximum and minimum scores reached for SxCMs (see Fig. 6) were calculated. These grades were obtained after the equations shown in Figure 2 were applied. The SxCM's results showed low grades but it was due to the fact that students had not received formal teaching about cost estimation drivers and they had complete freedom to develop their own Concept Maps. Hence, the students showed acceptable knowledge on cost estimation drivers despite not having received training.

MCMvsS1CMtoS61CM				
Average grade	Max. grade	Min. grade	Mean	Standard Deviation
4.15	6.42	2.69	4.18	0.98

Fig. 6. Phase one outcomes (First assessment)

As shown in Figure 6, due to low standard deviation, most of the students received around 4.2 points and an average of 4.15. In general, these scores represent an initial knowledge measure of them and the results can be considered a diagnostic test.

MCMvsS1CMtoS45CM				
Average grade	Max. grade	Min. grade	Mean	Standard Deviation
4.49	8.06	3.21	4.41	0.88

Fig. 7. Phase one outcomes (Second assessment)

Approximately one month later a second assessment was performed of the same task from the students which involved drawing a Concept Map. There was an increase of almost two points, from 6.42 to 8.06 (See Fig. 7). Additionally, more specific cost estimation factors were used by students. The mean score increased more than 0.2 points which is an indication of students gaining more knowledge about cost estimation drivers as a result of the training received. The standard deviation decreased which can be interpreted as grades getting closer to the mean, in other words, the spread between the highest and lowest grades decreased from Round 1 to Round 2.

Additionally, an analysis of the Scale Drive Factors and Effort Multipliers showed that 64.4% of students included at least one SDF on their SxCMs (See Figure 8). This indicates that students increased their knowledge about specific elements that impact project cost.

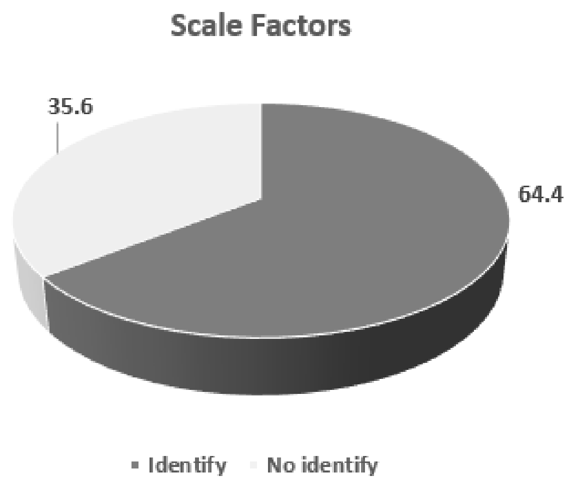

Fig. 8. Scale drive factors.

Moreover, an increasing number of Effort Multipliers were identified on SxCMs (See Figure 9) as shown by 73.3% of students including them on their SxCMs. This indicates that almost all students increased their knowledge about specific elements that influence a project cost as shown by their increase in their background about multiplier efforts.

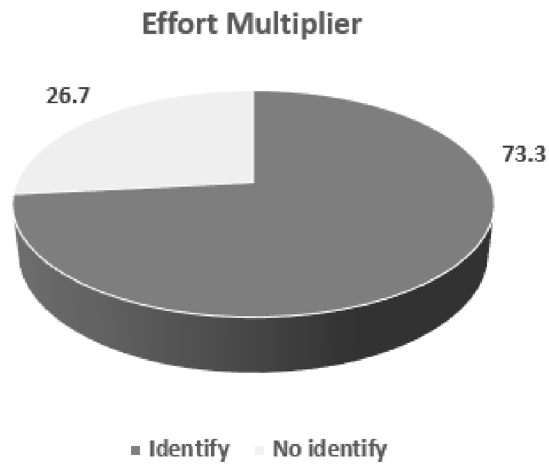

Fig. 9. Effort Multiplier.

Next, the percentage of students that included scale factors and effort multipliers were calculated. More than 50% of students included both of them (See Figure 10.). This analysis looked for synonyms or related terms of Effort Multipliers and Scale Drive Factors.

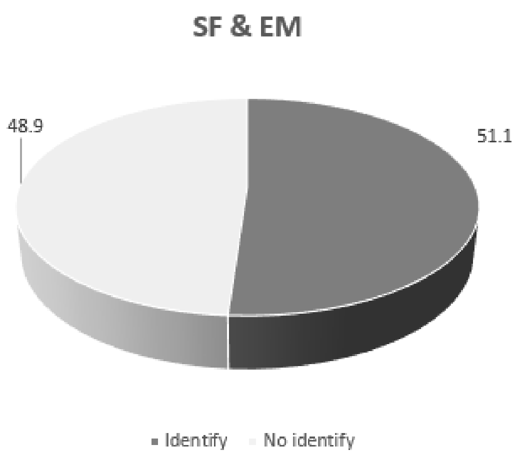

Fig. 10. SDF & EM together were identified.

Furthermore, the assessment rubric (See Table 1) was applied in order to identify aspects about Systems Thinking Competence #3 (STC#3). It was applied in the first and second assessment phase (See Figures 11-14). 60 SxCMs were analyzed in Phase 1 and 45 in Phase 2 –some of them were eliminated as a result of the Mann- Whitney U-Test. Both phases included aspects related with STC #3. There was significantly more evidence of STC #3 in Phase 2 (24%) compared to Phase 1 (7%). This result is illustrated in Figures 13 and 14. Results have been shown in two different ways in order to have a better understanding.

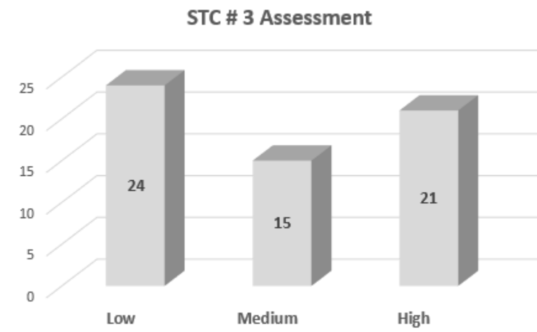

Fig. 11. Level of STC #3 identified. First assessment phase (N = 60)

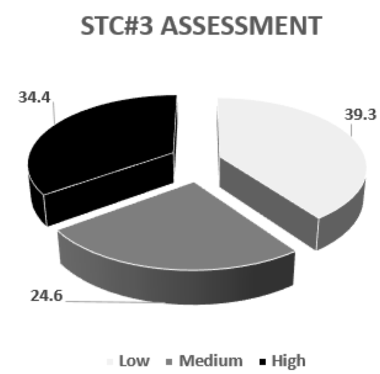

Fig. 12. Percentage of STC #3 identified. First assessment phase

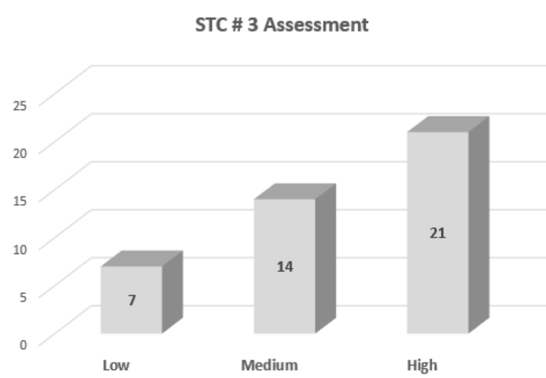

Fig. 13. Level of STC #3 identified. Second assessment phase. (N = 42)

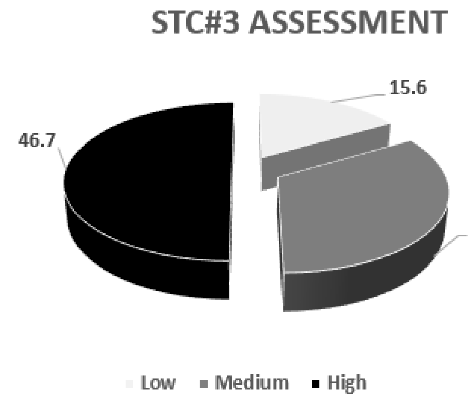

Fig. 14. Percentage of STC #3 identified. Second assessment phase

As an example, one SxCM is shown. The S19CMs (student 19 of 61 during Phase 1), is shown in order to demonstrate what kind of Student Concept Map was provided (See Figure 15). This student obtained a score of 4.6 points in Phase 1. 4.6 means a similarity of 46% with Master Concept Map, in other words, this student included 5 of 19 possible cost estimation drivers.

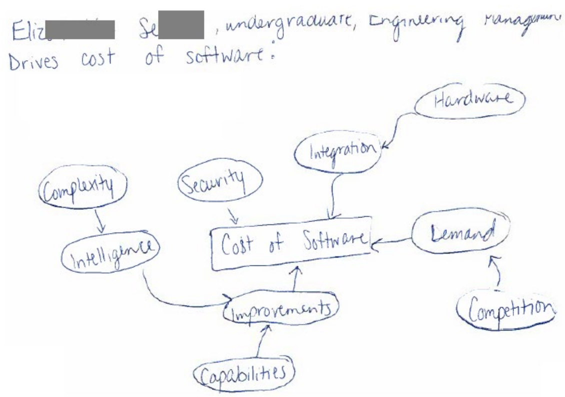

Fig. 15. S19CM. (First assessment phase)

The same student (Student 35 = student 19 in phase 1), but in the second assessment phase (Phase 2), received a final score of 8.1.

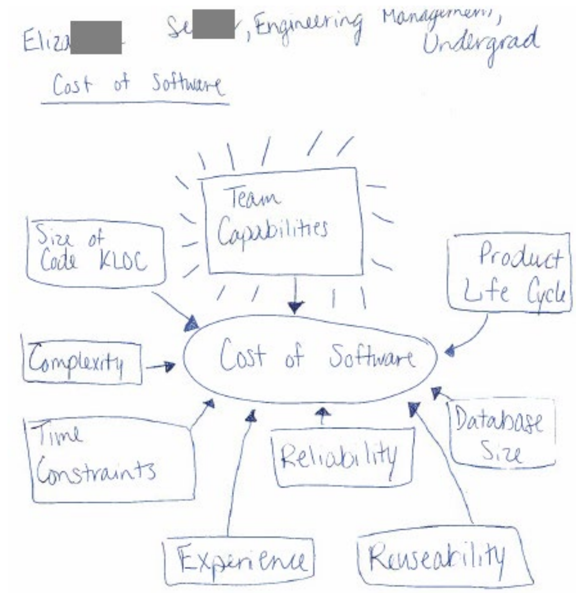

Fig. 16. S35CMs (Second assessment phase)

Table 2. Rubric to assess SxCMs vs STC #3

Rubric to assess STC #3 on SxCM						
Phase 2						
	Assesment STC #3			Elements Identified		
SxCM	Low	Medium	High	1	2	3
1	1			Economy		
5		1		Technology	Company	
8		1		Platform	Learning curve	
10			1	Investment	Platform	Profitability
11	1			Competition		
12		1		Copyright	Budget	
13	1					

This grade, 8.1, means a similarity of 81% with Master Concept Map as shown in Fig 16. In other words, student 35 included 13 of 20 possible cost estimation drivers which was an improvement of 3.5 points.

4.2. *Mann-Whitney Results*

The first Mann-Whitney U-Test applied to Estimation Cost Drivers included by students in their Concept Maps at first and second study gives us the next results.

The Null Hypothesis (H_0), and the alternative hypothesis (H_1) were defined to the first Mann-Whitney test. This was a measure of Cost Estimation Drivers included at first phase ($NCED_1$) compared to the number of Cost Estimation Drivers included at second phase ($NCED_2$).

$H_0 = NCED_1 >= NCED_2$

$H_1 = NCED_1 < NCED_2$

The sample size for the first phase and the second phase was n_1 =54, and n_2 =41. The median of Phase 1, and Phase 2 was 3 and 5 respectively (See Figure 17). The median represents the midpoint of a frequency distribution of Cost Estimation Drivers included in Concept Maps by Students in Phase 1, and Phase 2.

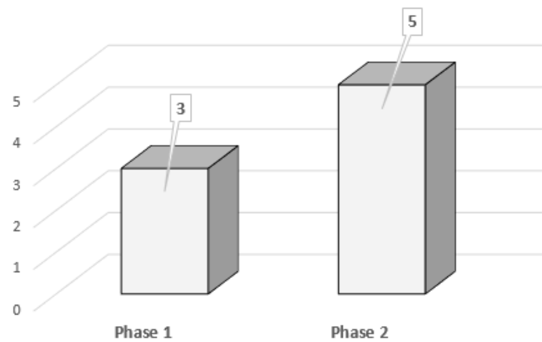

Fig. 17. Medians Phase 1 and Phase 2

Additionally, Figure 18 shows a histogram of Cost Estimation Drivers included in students' Concept Maps. This graph represents how many Cost Estimation Drivers were included in the Students' Concept Maps at Phases 1 and 2.

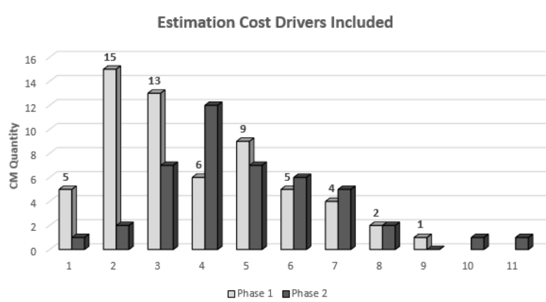

Fig. 18. CED included at CMs

The rank of Phase 1 and Phase 2 was calculated as $Rank_1$ = 2641, and $Rank_2$ = 2924 in order to do that, the data of Phase 1, and Phase 2 was rearranged from lowest to highest score while keeping track of Phase membership, and assigned a rank to each score. If there is a tie, all of the scores that tie receive the average rank of that set of scores.

After these calculations, the U parameter was calculated for both Groups. U_1 = 1889, and U_2 = 811 (See Figure 4). Hence U = 811.

Z_u was computed because our sample was larger than 20. After applying the equation (See Figure 5), the value obtained for Z_u was 3.49.

Since p-value>α (p-value=0.99, α=0.05). Hence the null hypothesis $H_0 = STCL_1 <= STCL_2$ cannot be rejected. The cost estimation drivers identified by students in Phase 1 are assumed to be less than or equal to the cost estimation drivers identified by students in Phase 2. Additionally, p(x<=Z=0.00095) which means that the chance of error rejecting H_0 is too high (99.9%). Therefore, the larger the p-value the more it supports H_0. This means that cost estimation drivers included by students in their Concept Maps at Phase 1 were lower than the cost estimation drivers included by students in their Concept Maps at Phase 2. However, when we estimate the common language effect size (U/n1*n2) =0.30, this is the probability that a random cost estimation driver from Phase 1 is greater than a random cost estimation driver from Phase 2. As a result, H_0 cannot be rejected.

The second Mann-Whitney test was applied to Systems Thinking Competency Level #3 demonstrated by students. The Null Hypothesis (H_0), and the alternative hypothesis(H_1) was defined.

$H_0 = STCL_1 <= STCL_2$

$H_1 = STCL_1 > STCL_2$

Systems Thinking Competency Level at Phase 1 and Phase 2 were defined as $STCL_1$ and $STCL_2$. The sample size for the first phase and the second was n_1 =54, and (n_2 =41). The medians for Phase 1 and Phase 2 was 2 and 3 respectively (See Figure 19). The median represents the midpoint of a frequency distribution of Systems Thinking Competence #3 levels reached in Concept Maps demonstrated by students in Phase 1 and 2, respectively.

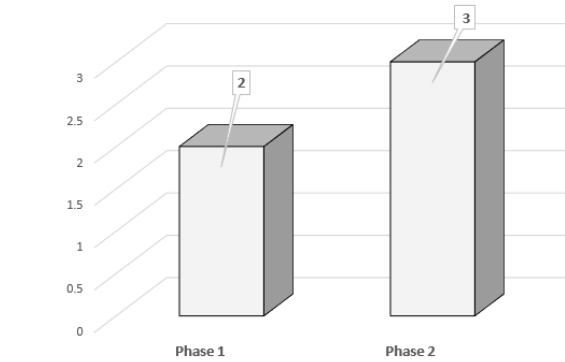

Fig. 19. STC#3 Medians

Additionally, Figure 20 shows a histogram of Systems Thinking competency #3's level demonstrated by students' Concept Map. This graph represents what level of systems thinking competence #3 was reached in the Students' Concept Maps at Phases 1 and 2.

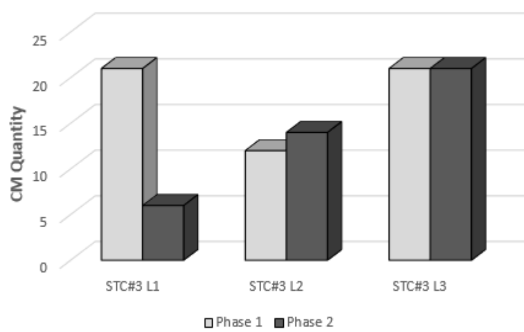

Fig.20. Systems Thinking Competency Level

The ranks for phase 1 and 2 were calculated as $Rank_1$ = 2641 and $Rank_2$ = 2924. To calculate the rank for Phases 1 and 2, the data were rearranged from lowest to highest score while keeping track of phase membership and assigned a rank to each score. If there is a tie, all of the scores that tie receive the average rank of that set of scores.

After these calculations, the U parameter calculated for both phases was U_1 = 1321.5, and U_2 = 892.5. Hence U = 892.5 because the $U_{1,2}$ with fewer scores is selected, in this case U_1 was selected.

Z_u was computed because our sample was larger than 20. After applying the equation, the value obtained for Z_u was 1.61.

Since p-value>α (p-value=0.97, α=0.05). Hence the null hypothesis H_0=$STCL_1$ <= $STCL_2$ cannot be rejected. The Systems Thinking Competence #3 reached by students at Phase 1 are assumed to be less than or equal to the Systems Thinking Competence #3 reached by students at Phase 2. Additionally, p(x<=Z=0.02288) means that the chance of error rejecting H_0 *is* too high (99.9%). The larger the p-value the more it supports H_0. This means that STC#3's level reached by students in their Concept Maps in Phase 1 were lower than the STC#3's level reached by students in their Concept Maps in Phase 2. However, when we estimate the common language effect size (U/n1*n2) =0.36, which is the probability that a random STC#3's level from Phase 1 is greater than a random STC#3's level from Phase 2. Finally, H_0 cannot be rejected.

The Mann-Whitney U-Test provided a quantifiable measure of the confidence in the results of this study.

5. DISCUSSION

Regarding RQ1 (How does ability to see relationships (STC #3) change over time as a result of learning cost modeling concepts?) while there was only one month between Phases 1 and 2, a statistically significant difference was detected. After students received training about cost estimation drivers, they were able to develop Concept Maps where more cost estimation drivers were included, and they were able to see more relationships. In other words, they increased the level of Systems Thinking Competence #3 as shown by the content of their Concept Maps. These results are summarized in Figures 13 and 14.

Regarding RQ2 (How do students' mental models of the factors that impact project costs change over time?), it is necessary to provide training or teaching where students get information about cost estimation drivers so that this information can be internalized by each student. This research had two phases with one month between them. During this time, students received information about what factors could impact project costs. The knowledge acquired allowed students to build Concept Maps with more cost estimation drivers included. These outcomes shown it is important include information about what Systems Thinking Competence is, and add information about the specific topic or area to be addressed. This information will be used to increase, in a relatively short period of time, students' ability to demonstrate Systems Thinking Competencies. Additionally, students were able to improve their ability to see relationships after they received more information about software cost estimation drivers which they were able to represent through Concept Maps.

This research assessed Concept Maps by applying an Adapted Holistic Scoring Method together with an Assessment Rubric. It is important to customize the methodology, mainly, when it cannot be applied in a direct way. The adaptation involved adding three equations: D, E, and F (See Figure 2). Additionally, involving an expert evaluator and modifying scale scores were necessary steps to analyze the raw data gathered.

A Mann-Whitney U-test was applied to Cost Estimation Drivers included in Concept Maps developed by students in both Phases 1 and 2. The changes in student content between these Phases was shown to be statistically significant. The null hypothesis $H_0=STCL_1 <= STCL_2$ cannot be rejected which means that the cost estimation drivers identified by students in Phase 1 are less than or equal to the cost estimation drivers identified by students in Phase 2. When Figure 17 is observed, Phase 1's median, and Phase 2's median show that 3 and 5 Cost Estimation Drivers were more frequently included in Concept Maps, respectively. Concept Maps developed in Phase 1 include less Cost Estimation drivers than Concept Maps developed in Phase 2. Hence, it is evident an improvement between Concept Maps developed in Phase 1 regarding CMs developed in Phase 2.

An additional Mann-Whitney U-test was applied to Level of Systems Thinking Competence #3 demonstrated by students when they develop their Concept Maps, in both Phase 1 and Phase 2. As a result, we can conclude that the changes between Phase 1 and 2 were statistically significant. In other words, the null hypothesis $H_0=STCL_1 <= STCL_2$ cannot be rejected which means that the STC#3's level reached by students in Phase 1 are less than or equal to the STC#3's level reached by students in Phase 2. In addition to Mann-Whitney U-Test we can see Phase 1's median and Phase 2's median is 2 and 3 respectively as shown in Figure 19. This means that STC#3's level reached in Phase 1 is less than STC#3's level reached in Phase 2. Hence, it is evident that there was a statistically significant improvement between Concept Maps developed in Phase 1 regarding CMs developed in Phase 2.

This research was applied to a limited sample of participants, which consisted of undergraduate and postgraduate students, which were recruited using a convenience sampling approach. Additionally, since the sample is homogeneous the outcomes have limited generalizability to other areas of engineering. Hence, the outcomes must be taken with caution since the sample size was limited to N = 45.

6. CONCLUSIONS

This research has shed light on a specific Systems Thinking competence (STC #3) by collecting evidence about STC #3 demonstrated by undergraduate and postgraduate students, even with limited or zero knowledge about what a Systems Thinking Competence is.

Collecting this kind of information can be useful when Systems Thinking Competencies must be taught. In other words, before a teacher or trainer plans to teach Systems Thinking Competencies, it may be beneficial to apply an initial diagnostic test in order to identify the level of knowledge in each competence. The results can be used to design a strategy to teach Systems Thinking Competencies. These actions could save training time, and reach desired objectives more quickly and more efficiently.

Outcomes indicated engineering students have some cost estimation knowledge. This makes sense given their engineering background and previous University coursework or work experience. In general, they have awareness of aspects that have to be taken into account when a project is developed and when a cost has to be estimated. For instance, they identified aspects that imply time and money.

Outcomes obtained can be useful in designing educational strategies for teaching cost estimation. Especially when systems thinking is a desired emphasis.

Additionally, this research showed that, despite engineering students not writing specific cost driver names, they identified them by concept area. Hence simply teaching specific cost estimation cost drivers will be required in order to ensure a high degree of competency among students.

Finally, the Mann-Whitney U Test was useful in showing that changes between Phase 1 2 were statistically significant.

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