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#### Understanding the Development of Teamwork Competency to Comprehend the Transformation in Systems Engineering discipline

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### Understanding the Development of Teamwork Competency to Comprehend the Transformation in Systems Engineering discipline

#### Abstract

The engineering practice is dynamic in nature, increasing in complexity, enhancing in connectivity, and growing in need for convergence among disciplines. Given the shift in the dynamic nature of engineering practice, there is an opportunity within Systems Engineering for transforming into a transdisciplinary discipline. The purpose of this study is to conduct a systematic review of the literature to obtain a comprehensive understanding of how teamwork has been used or proposed as a competency in the systems engineering competency-based frameworks in order to align with the transformation of the discipline. The results of the systematic review yielded key themes related to teamwork which have been proposed for comprehending the change in systems engineering discipline. Furthermore, when these results are combined with our previous work on teamwork, we are able to conclude that this study provides valuable insights to both academia and industry in the understanding of teamwork skills development processes in order to prepare the future engineering workforce and in the development of the curriculum for the systems engineering education vision 2030.

#### Background

The engineering practice is dynamic in nature, increasing in complexity, enhancing in connectivity, and growing in need for convergence among disciplines. Given the shift in the nature of problems and solutions, there is an opportunity within Systems Engineering for transforming into a transdisciplinary discipline [1], [2]. Sillitto et al. [55] describes Systems Engineering as a "*transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods*". According to Rousseau [3], transdisciplinarity can be used as a powerful problem-solving technique that brings in patterns and perspectives by crossing disciplinary boundaries and creating a holistic approach. Extending this definition, transdisciplinarity in systems engineering would mean going beyond the traditional "*engineering involvement*" to identifying and involving stakeholders from various disciplines with different worldviews to accomplish key fundamental principles of systems engineering [3].

In response to these opportunities, several competency frameworks have been developed, however, they have not been updated in several years based on the evolving role of systems engineering, the engineering practice, and aligning with the growing transdisciplinarity of the field [2]. As mentioned, collaboration is a crucial part of this transdisciplinary shift, hence, teamwork becomes a key competency that system engineers need to master. Yet, academic and industry leaders have not agreed on what important teamwork attributes are necessary to comprehend the transformation of the systems engineering discipline [4]. Furthermore, research is required on how to effectively develop teamwork within the systems engineering competency-based framework to adapt to transdisciplinary systems engineering.

#### Purpose

The purpose of this study is to conduct a systematic review of the literature to obtain a comprehensive understanding of how teamwork has been used or proposed as a competency in the systems engineering competency-based frameworks in order to align with the transformation of the discipline. To this effect, the research questions guiding this study are two pronged: First, we wanted to understand: RQ1: In what contexts have teamwork within Systems Engineering been elaborated upon? Next, we sought to examine: RQ2: What aspects of teamwork have been proposed or studied in academia and industry as part of the transformation of the systems engineering discipline?

#### Literature Review

Teamwork has been highlighted as an important skill in several systems engineering competency models. The International Council on Systems Engineering (INCOSE) provides a competency model and formal certification for individuals achieving competency in a specific area of competency [52]. In addition, there are several domain and industry specific competency models which highlight teamwork as an important competency. The United States Department of Defense and NASA have established competency models in systems engineering which highlight teamwork as an important professional skill for systems engineers [53] [54]. INCOSE highlights team capabilities for systems engineering including the team composition for a system engineering project, identifying and developing the right knowledge, skills, and abilities of systems engineers [52]. The US DoD emphasizes team building competency by inspiring and fostering team commitment, spirit, and trust. Also, by establishing cooperation and team motivation to accomplish project goals [54].

The overall systems engineering competencies have been updated since the transformation of the systems engineering discipline, however, teamwork as a competency has not evolved since then. The established competency frameworks under DoD, NASA, and INCOSE are more than five years old and require an update in some of its aspects including teamwork. This paper calls for a better understanding of what aspects of teamwork have been discussed in the last five years of the systems engineering discipline since the discipline shift into a transdisciplinary field.

#### **Mixed Methods Systematic Review**

The aim of the study, as elaborated earlier, was to find out how teamwork has been used or proposed as a competency in the systems engineering discipline. This systematic review addresses the gap in literature specific to a dearth of studies synthesizing articles describing teamwork as a competency in systems engineering contexts. Thus, while there exist reviews, both systematic and traditional, which address the broader topics of systems engineering and teamwork individually, there is little work elaborating on teamwork as a competency for Systems Engineers of the present and future.

A mixed methods systematic review was used to identify the important teamwork attributes as described by the authors of the papers. The EPPI Centre [5] recommends aligning methods used in the systematic review process to the research questions of interest driving the review. Petticrew et al. [6] advise use of quantitative methods to answer review questions related to *"what works?"*, and qualitative methods to answer review questions related to *"what matters"*. Additionally, a mixed methods approach to systematic reviews is often described in the literature as mixed methods research synthesis [7]. Heyvaert et al. [8] state that while conducting systematic reviews, mixed syntheses, as compared to *"un-mixed syntheses"* may provide 'more complete, concrete, and nuanced answers to complex research questions. This research synthesis is backed by an interest in summarizing both what works as well as what matters, in terms of understanding how teamwork is described in systems engineering contexts. We wanted to not only summarize descriptive insights based on where and when these conversations were happening (e.g., conferences versus journals, year, etc.) but also dive deeper to understand their contexts (e.g., how was teamwork described and for whom).

#### **Data Collection**

This study follows Borrego et al. [9] structural approach to systematic reviews in engineering education which begins with first defining suitable search keywords that align with the purpose of study, followed by searching for relevant literature and finally performing necessary analysis in the end. For this study, first, the relevant sources of publication including book chapters, academic journals, conference papers and published thesis were identified regarding teamwork in systems engineering. We analyzed relevant sources using two search terms together, first key words related closely with teamwork including "team\*" or "teamwor\*". Secondly, key words closely related with Systems engineering include "system\* engineer\*. We used the Engineering Village as our database. Engineering Village was chosen due to its comprehensive repository which indexes four engineering databases in their search interface- Compendex, Inspec, NTIS and Knovel, capturing publications from over 5000 engineering journals, conference papers, book chapters, dissertations, etc. Next, we laid down inclusion criteria - an inclusion criterion to help us identify primary articles included in the review, informed by the purpose and research

questions for the research syntheses [9]. Our study was guided by four inclusion criteria, one at the abstract level search, and the rest during the appraisal level at preliminary, full text, and final appraisals.

Our inclusion criteria were:

- IC1 (in the abstract screening stage): To capture the full breadth of existing research, any study that mentions terms relevant to teamwork (eg: teams, team working, group work, collaboration, team competency) in the systems engineering discipline was included as part of the review.
- IC2 (in preliminary appraisal stage): Papers included as part of the review that explicitly mentioned systems engineering as a discipline at any level of education or in any setting (academia or industry)
- IC3 (in full text appraisal stage): Papers included as part of the review that explicitly detailed the connection between the use of teamwork theory, foundations, knowledge, abilities, framework, best practices used in the systems engineering discipline.
- IC4 (in final appraisal stage): Papers included as part of the review that described results, discussion, conclusions and implications related to teamwork in the systems engineering discipline.

Essentially, we used an adaptation of the Search-Screen-Appraise methodology advocated by Borrego, et al. [9]. Figure 1 below provides a visual representation of the steps in our data collection process, and the number of articles filtered at each step.



Figure 1. Steps in the data collection process using Search-Screen-Appraise methodology

#### **Data Analysis**

Once the articles were identified, we first collected all demographic information (e.g., type of publication, type of paper – research, non-empirical, year of publication, etc.). We also got rid of duplicates, and only considered articles that were from peer reviewed sources and were available in English. Next, we embarked upon a thematic analysis as our approach to discovering themes across the articles based on analyzing the descriptions and contexts for teamwork as a competency based on those detailed by the authors in their publications [10]. Thematic analysis is defined by Braun & Clarke [10] as a method of identifying, analyzing, and reporting patterns within the qualitative data. In addition, Robson & McCartan [11] posit that state thematic analysis as a generic qualitative method that allows data to emerge from patterns after implementing open coding of the qualitative data. The coding process to find out different themes relevant to teamwork and systems engineering was guided by traditional qualitative coding procedures [12].

#### Results

As introduced earlier, our study was guided by two research questions: RQ1: In what contexts have teamwork within Systems Engineering been elaborated upon? and RQ2: What aspects of teamwork have been proposed or studied in academia and industry as part of the transformation of the systems engineering discipline? While the answer to the first question was answered using descriptive insights from the collection of papers included in our review, the second question was answered using a more qualitative approach, deep diving into the contexts and definitions used in each individual paper and drawing themes across the entire collection.

Our review yielded 37 scholarly papers that were relevant to the purpose of our study. From the records, all the scholarly papers were either journal articles or papers published in different conference proceedings. Specifically, there were 26 conference articles and 11 journal articles that were identified for this study. These 37 scholarly papers were used to derive insights for our two research questions.

#### RQ1: In what contexts have teamwork within Systems Engineering been elaborated upon?

In terms of the distribution of the field where the scholarly papers were published, most of the identified papers were published in the field of Engineering Education. In addition, the publications were evenly distributed across different fields relevant to systems engineering. The International Council on Systems Engineering (INCOSE) and Institute of Electrical and Electronics Engineers (IEEE) conferences were among the top two venues where the papers were published. Figure 2 shows the visual of the publication field distribution from the identified scholarly papers.



Figure 2. Distribution of field of publication

In terms of year of publication, there was an initial upward trend from 2016 to 2018 as shown in figure 3, but the publications fell again from 2019 onwards. In addition, the number of journal papers have been consistently low over the last five years.



Figure 3. Year wise distribution of scholarly papers

To answer our research question, the scholarly papers were divided into *Academic* and *Industry* contexts. The *academic* context referred to any paper that was relevant to academic research and practices in engineering. The *industry* context referred to any paper focusing from the industry perspective. Figure 4 shows the distribution of the papers with respect to academic and industry contexts; the findings show almost even distribution with papers from industry perspective only slightly lower than academia. Specifically, we found 17 scholarly articles focusing on industry perspective and 20 focusing on academic settings.



Fig. 4. Academic versus industry context publications

While looking into the details of the paper, we were interested in understanding the research approach and method used for the scholarly papers which were relevant to our study. In terms of research approach, most of the papers did not specifically mention approaches including qualitative, quantitative or mixed methods. These papers were mostly non-empirical or conceptual papers. In addition, the papers which mentioned the research approach were majority qualitative papers as shown in Figure 5. Specifically, our results yielded 32% qualitative approach, 24% quantitative approach and 5% mixed method approach.





Figure 6 highlights the research methods used for the identified scholarly papers. The top three research methods used were Case study, Conceptual or non-empirical and Lessons learned or curriculum development. The top three research methods used show that the purpose of studying or proposing teamwork aspects in systems engineering as a new discipline is relatively new.



Figure 6. Research Method used in the scholarly papers

## **RQ2:** What aspects of teamwork have been proposed or studied in academia and industry as part of the transformation of the systems engineering discipline?

To understand how different teamwork aspects have been proposed or studied in the systems engineering discipline, a thematic analysis of the identified 37 scholarly papers was conducted. As discussed in the methodology section, using thematic analysis allowed patterns to emerge from the data after implementing an open coding approach from the scholarly papers that helped us find out different themes relevant to teamwork aspects and systems engineering.

From the thematic analysis, we were able to identify five categories based on the patterns that emerged from full-text screening of the identified papers. These categories emerged based on specific teamwork aspects discussed in the papers. Included in the categories are *Improvement, Data-driven optimization, Definition in SE, Teamwork attributes and Teamwork learning*. The five emerging categories were discussed with all the authors until an agreement was reached. Table 1 highlights each of the categories with their respective definitions.

Categories	Definition	Authors
Improvement	Evidence/strategies of the current gaps, challenges or improvement opportunities towards effective teamwork	[13]–[22]
Data-driven team optimization	Recommendations or decisions of effective teamwork using data-driven approach	[23]–[27]
Definition in SE	Defining teamwork competency or capability in the Systems engineering discipline	[28]
Teamwork Attributes	Specific teamwork characteristics necessary in systems engineering	[29]– [40]
Teamwork learning	Teamwork training, development or teaching to facilitate learning in the workplace or classroom	[41]– [49]

**Table 1.** Teamwork categories and their corresponding description and author reference

A detailed distribution of how each of the categories were represented in our results is shown in Figure 7. The top three categories emerged were Teamwork attributes, Improvement and Teamwork learning. In the following section, we summarize and provide a detailed explanation of the five categories.



Figure 7. Category counts from the Thematic Analysis

#### Teamwork attributes

According to our results, one of the most common categories studied in systems engineering discipline was teamwork attributes. The purpose of these papers was to emphasize on the specific teamwork characteristics required in systems engineering. In our analysis, we found 12 papers that focused on different teamwork attributes in systems engineering. Specifically, there were nine papers that highlighted the necessary teamwork attributes required in industry and three papers in Academia. From the industry perspective, different systems engineering competency models presented the important teamwork characteristics a systems engineer should possess in the engineering discipline [31], [32], [34], [36], [40]. For example, the US Department of Defense has created a comprehensive systems engineering competency model that mentions teamwork attributes including commitment to goals and mission, managing the group process by leading and building teams and providing technical direction for use in defense acquisition [32]. Leslie [31] presented an engineering competency model that promotes an understanding of the global systems engineering skill sets where teamwork attributes including open and effective

communication, commitment to team objectives and goals, psychological safety and building interpersonal relationships were emphasized. For a successful systems engineering leadership, Kemp et al. [34] suggested useful principles that would help guide practitioners developing effective systems engineering teams. Team composition was one of the most important teamwork attributes highlighted where selecting team members with the right attitudes, beliefs and culture is important for the success and sustainability of a systems engineering team. In addition, Delicado et al. [36] recommended the inclusion of T-shaped specialty engineers in a systems engineering team. A T-shaped specialty engineer along with system engineers can help divide tasks according to their respective expertise and help communicate and collaborate effectively.

From the academic perspective, studies from undergraduate engineering project teams focusing on systems engineering or building systems provided evidence of important teamwork attributes. The use of these attributes provided successful project completion among student teams [30], [35], [38]. Similar to industry recommendations, the academic evidence of teamwork attributes include well-functioning project teams with open and clear communication, interpersonal relationship among team members and perform tasks responsibly based on individual's expertise in to accomplish project goals [30], [35], [38].

#### Improvement

From our analysis, we identified 10 scholarly papers that emphasize evidence of the current teamwork gaps and challenges in the systems engineering discipline and provided recommendations for improvement opportunities towards effective teamwork. Specifically, there were six papers that highlighted the challenges and opportunities in industry and four papers from the academic perspective. In industry the key challenges of teamwork highlighted were lack of coordination among virtual and geographically distributed team members, challenges with communication and team decision-making while working on systems engineering projects [17], [18], [20], [21]. Kindarto et al. [17] further recommended authentic leadership and participative decision structures to gain team performance. Wang et al. [18] and Laitinen et al. [21] suggested the concept of collaborate in real time and in the same virtual environment using virtual reality technology that might help in channeling proper communication and coordination among team members.

Similar to industry, several papers in academia focused on understanding teamwork challenges and opportunities for student teams while working in systems engineering projects. Key challenges for student teams include lack of conflict resolutions and social flexibility among engineering students and difficulties in multidisciplinary team interpersonal skills. Authors identified these challenges among engineering students and led initiatives to overcome them. After finding out the lowest scores among systems engineering students in teamwork skills, Hanbazazah [13] and Sohoni et al. [15] identified the lowest scores in teamwork skills for each student and developed them by investing time and effort throughout the semester focusing on improving at the individual level. With respect to multidisciplinary teams, Crespo et al. [16] identified several benefits of working in multidisciplinary teams which results in developing more complex, deeper and innovative project outcomes. However, it was found that most student teams used the '*divide and conquer*' method of delegating tasks which resulted in lack of coordination when it came to explaining unforeseen issues related to their project design solutions [19].

#### Data-driven optimization

In terms of the Data-driven optimization category we found five scholarly papers from our analysis that emphasize on the use of data-driven approaches for teamwork effectiveness in systems engineering. From the industry perspective, there were two papers which recommended the use of frameworks using data-driven optimization that would help enhance teamwork performance. These frameworks would help suggest teaming recommendations including team challenges, instructions and development processes for teamwork effectiveness [23], [24].

Similarly, in academia, several authors emphasize the use of data-driven simulation frameworks to help the shortcomings of student-led projects in both teams and individuals. For example, Bakhtadze et al. [25] use an incentive model that would help instructors create project teams and manage individual students' knowledge and skills working in teams. Khuankrue et al. [27] use an agent-based simulation model for identifying different levels of failure in student projects including individual and team failures and recommend future opportunities for instructors to help them overcome and achieve project success.

#### Teamwork Learning

The teamwork learning category was among the top three categories identified from our analysis. Specifically, we found eight scholarly papers that mention the use of teamwork training, development or teaching to facilitate learning both in academia and industry. From the industry perspective, we found one paper that specifically discusses this category. Jean et al. [42] developed a professional development program that was developed in collaboration with industry leaders and regulatory bodies to engage a diverse group of system engineers with key learning objectives for establishing strong interpersonal skills.

The teamwork learning category was significantly higher from the academic perspective. We found seven scholarly papers that specifically highlight this category. The papers emphasize on the use of several strategies including program development, integrating problem-based learning,

teaching strategies that helped them understand teamwork competencies and improve team-based learning [41], [43]–[49]. For example, Garcia et al. [41] introduced a model-based system engineering framework that helps build technical leader competencies and improve learning outcomes and team function in a multidisciplinary team project. Several papers highlight the integration of Problem-based learning (PBL) into a systems engineering course [45], [46], [48]. For example, Magalhaes et al. [45] emphasizes the integration of Problem-Based Learning (PBL) and Conceive-Design-Implement-Operate (CDIO) methodology in a systems engineering course that helped develop social and teamwork skills among students and establish cooperation between students and teachers. Some of the comments included from the reports of this course are highlighted below

"The effective teamwork helped to develop the spirit of mutual aid and cooperation that was established, inside and outside the group"; and "Support of the teachers, who not only helped and lent materials but also encouraged us not to give up when things went wrong".

#### **Definition in SE**

We found only one paper in our analysis that defines '*teamwork competency*' from the systems engineering perspective. We decided that this category warrants its own due to its distinct difference from the other categories, and its contribution in highlighting teamwork as it relates to the transformation within the systems engineering discipline. Wasson [28] highlights the need for reestablishing SE core competency and recommended the following teamwork capability in systems engineering, "*The ability of a team to produce a desired outcome under a predefined set of conditions based on a specified Measure of Effectiveness (MOE) & efficiency*".

#### Discussion

The results from the research approach and methods show that we are still in the initial phase of the systems engineering discipline transformation and in future more empirical research is required to validate the conceptual models and lessons learned in both academia and industry. In terms of industry and academic contexts, the even distribution of the papers shows that understanding teamwork competency in systems engineering has been given equal importance both in academia and industry.

From our thematic analysis results, academic and industry leaders need to continue focusing on the teamwork themes highlighted in order to align with the transdisciplinarity of systems engineering. Data driven frameworks are still in the conceptual phase and require more empirical evidence to prove that these are well-established approaches for both academic and industry leaders to use as a tool or technique for teamwork effectiveness. However, the importance of using disruptive technology has been highlighted in our previous study which shows the necessity of using data-driven optimization for future transdisciplinary engineering teams [50].

Improvement in academia is similar to our previous finding in a different engineering discipline but the importance of identifying the gaps and pro-actively intervening to improve teamwork skills at individual level and for overall team performance [51]. In addition, our results show the use of PBL methodology in systems engineering courses to help improve several learning aspects among students including teamwork skills. This finding is similar to our previous research where PBL has been an important methodology in most of the engineering disciplines to help improve student learning including teamwork [51]. The primary reason for finding only one paper that defines teamwork competency in systems engineering discipline was due to the use of one database for our systematic review and limiting the number of years (2016-2020) for which the inclusion criteria did not capture the definition beyond our results.

#### **Recommendations and Conclusion**

Based on the results from our study, we want to provide both industry and academic leaders focusing the systems engineering transformation into the transdisciplinary field with some recommendations that would help guide through the transition. The following are the specific recommendations from our results.

- Several teamwork attributes have been emphasized both in academia and industry which highlight the importance of teamwork effectiveness in systems engineering. For instructors, these attributes can be used as a guide for teaching and training engineering student's teamwork skills. Also, for industry leaders, these attributes can be used to help develop teamwork skills for engineers in the workplace.
- Multidisciplinary teams allow better project outcomes; however, it is important to understand that multidisciplinary teamwork is different from traditional teamwork and instructors should provide training and proper guidance pertinent to multidisciplinary teamwork in order to create a successful team project.
- The importance of problem-based learning in systems engineering courses is another important teaching strategy that helps in developing teamwork skills among students. This integration strategy of PBL methodology has shown more cooperation between students and teachers in systems engineering. PBL can be integrated with other systems engineering methodologies based on the course requirement and learning outcomes.
- Further empirical research is required in order to establish the use of data-driven simulation models and framework for teamwork effectiveness in systems engineering. When using simulation models or framework highlighted from our study, researchers should validate them with empirical evidence for successful implementation.

• The definition of teamwork capability in systems engineering at high competency level by Wasson [28] can be used as one of the objectives for learning outcomes both in academia and industry.

Systems Engineering as a field is in its nascency. In the United States, for example, we are only now seeing course and degree offerings related to Systems Engineering focus. However, as we work on developing and growing the field, there is tremendous value in understanding the focus from both academic and industry leaders on what competencies are important and how these could be developed among future engineers. While there are several important competencies, our review emphasizes the importance of teamwork as a competence within systems engineering by highlighting how both academia and industry have described it. It is hoped that practitioners from both industry and academia find value in this comprehensive and systematic capture of thoughts based on literature from the past five years, thus paving the way for the future of this field and work on building these competencies among new graduates.

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