Systems Engineering Education Ecosystem Portal

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***Abstract*— In this Work in Progress, we believe that our education systems are not capable of evolving at the rate necessary to meet the challenges presented by rapidly changing technology epitomized by Industry 4.0 and the digital transformation. In particular, there are relatively slow and inaccurate feedback mechanisms for the academic program content needs of employers, students and universities. The objective of this research is to create the feedback mechanisms and interactions by which educators, students and employers can communicate their specific educational capabilities, desires and needs, that will provide the dynamic feedback necessary to accelerate the development and evolution of educational programs.**

Keywords—education ecosystem, engineering competencies, educational program feedback, systems engineering

I. Introduction

A. Motivation

We believe that our education systems are not capable of evolving at the rate necessary to meet the challenges presented by rapidly changing technology epitomized by Industry 4.0 and the digital transformation. In particular, there are relatively slow, inaccurate, indirect and incomplete feedback mechanisms between the needs of employers, students and universities at the level of program content development and evolution [1-3]. While a number of ranking systems provide feedback on the strengths of programs at an aggregate level particularly with respect to research strengths, it is difficult to gauge the relative strengths and weaknesses of a graduate academic program and how these match with a student's or employer's interests. One size does not fit the needs of all students and employers. In addition, there is little feedback between academic institutions. The objective of this research is to create and assess the feedback mechanisms by which educators, students and employers can communicate their specific educational capabilities, desires and needs, in order to provide the dynamic feedback necessary to accelerate the evolution of educational programs.

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B. Discipline Focus Area

This research focuses on the discipline of Systems Engineering (SE) which in its nascence is extremely broad, ill-defined, and rapidly changing. This can be seen immediately in the revised definition of Systems Engineering by the International Council on Systems Engineering, INCOSE [4]: "Systems Engineering is 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. We use the terms "engineering" and "engineered" in their widest sense: "the action of working artfully to bring something about". "Engineered systems" may be composed of any or all of people, products, services, information, processes, and natural elements."

While the primary focus of this research is initially on US academic institutions, it is applicable to systems engineering graduate programs worldwide. The initial impact of this work is on the systems engineering academic community. To date, there are no easy means by which to compare systems engineering masters programs. Transparency is expected to influence the enrollment decisions of students into masters programs and the outreach activities of employers. Both of these actions, along with exposure to the curricula focus areas of top programs, will effect considered change in academic programs. The foundational knowledge from this research will enable the adoption of this approach by other graduate engineering disciplines, and even baccalaureate engineering programs, providing effective feedback to the evolving needs of STEM education.

C. Vision

The vision of the Systems Engineering Education Ecosystem SEEE project is to create a ***collaborative ecosystem*** in which ***systems engineering educators*** can interact with ***SE employer partners, practitioners,*** *and* ***students*** to search, compare, define,

and exchange program objectives and resources to enhance educational impact. This vision is motivated by the exponential pace of societal and technical change that underlies the need for SEEE, and also demands that we design an adaptive resource that can stay one step ahead of the surrounding ecosystem [5-7]. The objective of this paper is to describe how a competencies framework supported by an internet portal can be used to enable the creation of this ecosystem.

II. SEEE Description

A. Research Platform

Unlike existing slow, inefficient and indirect means, the research platform for this work is a collaborative online environment in which systems engineering educators can efficiently and effectively interact with employer partners and students to define, create, and exchange curricular and pedagogical resources to enhance educational impact. This website provides a portal by which students, universities and employers of systems engineers can review, compare and match the systems engineering competencies that are important to them. Through this transparent communication, best matches can be found and the discipline of systems engineering can evolve to meet the emerging needs of the systems communities. Underlying the collaborative effort is a desire, while preserving the uniqueness of systems engineering programs that speaks to particular varieties of students and professions, to enhance commonality among programs where it is beneficial, and to establish a community - supported ideal of systems engineering education that will eventually create some commonality in the meaning of a systems engineering graduate degree among employers and students, and thereby enhance the value of all the programs.

B. Use Cases

A number of use cases have been defined for each of the three critical stakeholder groups: students/professionals, employers and universities are described below.

Students and professionals can use the website to understand the various competency levels that are involved in systems engineering by that and other names such as industrial and manufacturing engineering, and program management. This information will allow the self-assessment of one's proficiency levels in these areas. Students and professionals can search out and find the desired proficiency levels that are desired for different positions by employers of interest. Coupling the information of desired competencies and actual capabilities determines personal competency gaps which can then be used to match with relevant academic programs. Students and professionals who have taken these university courses can provide feedback on the veracity of the mapping that universities have provided between the courses and the competencies. Finally, students and professionals who are interested in specific positions can post their profiles and permit certain employers to review them, and also actively reach out to these employers with their qualifications for future employment.

Employers can use the website to create position competency postings that can be used as reference for potential future employees, and also to describe their priorities to help influence academic programs. The employers can actively search for matches with future employees, or passively allow potential employees to reach out to them. Employers can also look for university programs that match their needs and reach out to recruit students from these programs, and/or actively engage in supporting these programs through research and other forms of funding. Finally, employers can look at the desired competency needs from others in the industry or other leading industries to see if their desired competencies are in alignment with those in other fields.

Universities can use the website, much like students, to see how their programs support the needs of their industrial and governmental sponsors. Like employers, universities can enter their profiles as a means to connect with potential students and industrial partners. Finally, universities can use this information to benchmark the focus areas of their programs with those of their academic competitors and partners. Each of these efforts provides feedback that can be used to develop new programs and update existing ones.

While we believe that this list supports the majority of the use cases, it is expected that additional unexpected use cases will emerge through stakeholder use. Feedback mechanisms have been provided to allow users to request additional support for these new uses.

C. Competency Frameworks

This research developed a systems engineering competency taxonomy based on a thorough review of existing systems engineering and engineering competency frameworks [8-11], interviews with industry, and anticipation of the future needs of the discipline. The resultant framework consists of all of the INCOSE framework [8], with some notable additions, categorized into the four major categories:

- **Lead** – Personal and interpersonal competencies related to emotional IQ, ethics and professionalism, critical thinking, teamship and communication skills. These capabilities serve to amplify the impact of the other competencies through others.
- **Understand** – Analytical competencies relating to understanding, creating and using systems models, including systems thinking, modeling and simulation, experimentation, and analysis and decision making. These competencies provide support for decision making.
- **Design** – Synthesis competencies that enable the system design through the lifecycle of conceptualization, architecture, implementation and sustainment. These competencies support the creative design process including design thinking, engineering design, and systems engineering.
- **Realize** – Management and control competencies that support the actual realization of systems including business fundamentals, lifecycle management, monitoring and control, and operations. These competencies enable the realization and execution of the engineering of systems.

An iterative approach will be taken to update and modify this framework based on data gained through prototyping exercises and website interaction of the three stakeholder groups providing a dynamic means of keeping the competencies relevant to all parties.

III. SEEE Portal Implementation

A. Description

The centerpiece of the SEEE web portal is a competency questionnaire and visualization that enables visualization of approximately 40 competencies relevant to systems engineering practice. The portal is additionally designed to provide tailored experiences to each ecosystem user, whether they are a practitioner/student, an employer, or representing a university program.

Key functions of the SEEE portal are (1) Entering of a competency questionnaire or inventory, on behalf of oneself (as a student or practitioner user), a systems engineering position type (as an employer user), or a systems engineering program (as a university user); (2) Viewing one's own competency result in a concise visualization; (3) Comparing one's own visualization to another; and (4) Searching to find similar or complementary profiles. Each user profile also has the option to enter some basic information to facilitate networking.

Similar profiles are best matches based on the shortest distance between normalized competency scores across all areas, whereas complementary profiles are best matches based on the largest distance. See Figure 1 for an example visualization that would depict a user's competency data. The ability to search and compare profiles is a key mechanism that allows users to engage with each other and transparently communicate about the skills that are desired (e.g., by students, practitioners, and employers) and the skills that are offered (e.g., by universities, practitioners, and students).

As users of all three stakeholder groups complete competency questionnaires and engage the search and compare functions of the site, it is expected to see the evolution of clusters of related competency profiles, as well as convergence between clusters of competencies sought by students, practitioners, and employers and clusters of competencies offered by universities, practitioners, and students.

B. Design

The SEEE Portal has been designed and developed according to a Design Innovation (DI) process [12-14]. Design innovation blends principles, methods, and processes from design thinking, systems engineering, engineering design, and business innovation. DI emphasizes co-creation with people, from individuals that use or have stake in a design, to organizations and communities. Empathy towards user needs drives towards societal value, which for SEEE means accessibility, desirability, and value for all members of the extended systems engineering community worldwide.

The Design Innovation process has four major phases, which have been implemented as a series of short sprints to rapidly iterate and integrate stakeholder and community feedback. [Discover] is the first phase, consisting of user research and interviews. The SEEE process has continually engaged in discovery to ensure the design and implementation are aligned with user expectations, is easy to use, and fulfills intended functionality. [Define] is the second stage, consisting of reframing and consolidating insights. This convergent phase ensures that the most essential insights are distilled into opportunity statements regarding user experiences and technical functionality. [Develop] is the third stage, and is an ideation phase. Here, diverse inspiration is leveraged to consider how specific opportunity areas may be addressed through design. [Deliver] is the fourth and final stage, where prototypes are created and tested. Prototyping as design and implementation moves from subsystems to system ensures rapid evaluation and evolution.

IV. Current Status

A. Initial User Testing

An early prototype of the SEEE Portal was demonstrated at the INCOSE International Workshop on January 31, 2021. Participants were invited to explore the prototype website according to one of three stakeholder groups (Students and Practitioners, Employers, and Universities) and provide feedback from their perspective. There were approximately 40 participants in the workshop and 26 participants in an asynchronous survey that allowed for extended feedback.

Twelve key areas of insights were derived from stakeholder feedback of this early prototype. Some examples of new insights gained from this feedback include Privacy and Personalization to allow detailed control over what information is included in a public profile view; Information Integrity and Metrics for users to ensure data validity and view aggregate trends over time; and Collaborative profile creation functionality for University and Employer profiles. These user insights informed the next round of development.

Initial user testing also showed that the SEEE Portal is already able to spark the kind of discussion and feedback that is central to the collaborative ecosystem model. There was productive conversation around competency areas helpful to include for different stakeholder groups (e.g., Experimental Design), and the value of comparing profiles to learn about the community and trends that may emerge.

B. Development

The SEEE Portal has progressed through four major development stages. The first stage was low- and medium-fidelity prototypes of subsystem components (questionnaires, profile pages, visualizations, database storage and retrieval mechanisms) [15]. The second stage was an alpha website, built in Javascript and React library. The alpha SEEE Portal prototype focused on user experience considerations. The third stage is a beta SEEE Portal prototype, emphasizing the functionality of the portal experience. The beta prototype is developed on the planned final website platform, Progress Sitefinity which allows customization in CSS, C#, and asp.NET languages. The fourth and final iteration will be the full first release in the Sitefinity platform, combining an updated user experience and updated functionality from testing and feedback after each previous development stage.

C. Outreach

Outreach efforts are being made in parallel with the website development to ensure that it will be populated with relevant competency profiles and reaches critical mass to be an effective tool for feedback in the systems engineering ecosystem. The three critical stakeholder groups are: 1. students and working

professionals with an interest in systems engineering graduate education, 2. the employers of graduate students with systems engineering skills, and 3. the academic community who serve the systems engineering educational needs.

INCOSE will be used as a channel to students and working professionals through various outreach programs, currently serving over 17,000 members. Employers will be reached through INCOSE's Corporate Advisory Board representing over 120 organizations that employ systems engineers. Finally, academic institutions will be reached through INCOSE's Academic Council with over 30 members representing eight nations and 23 US academic institutions. Explicit outreach efforts will be made to reach all 94 of the US NEWS rated US programs and the 307 global institutions that appear in the Worldwide Directory of Systems Engineering and Industrial Engineering Programs.

V. Conclusions and Future Work

The SEEE Portal is a very unique ecosystem in the engineering profession. SEEE will provide cooperation and competition among all stakeholders in the systems engineering community. SEEE will provide a healthy exchange of research and information in the development of new systems engineering methodologies and tools as the profession evolves. It will create worldwide participation from multiple countries and their practices in systems engineering. It will also provide a platform to establish Systems engineering research needs in a digital world that is evolving daily.

The SEEE Portal is expected to reach beta status with a first release in the summer of 2021. This will enable the research described in Section I through allowing periodic review of the user and competency profiles entered to the site, as well as analysis of user traffic including site visits and number of returning visitors which may indicate uptake in a community. A number of metrics will be used to determine the success of this project:

- Ability to communicate university program content, such as the number and percentage of US Systems Engineering programs entered into the system for comparison, and feedback from users on the usefulness and clarity of the data, and suggested changes.
- Ability to communicate position availability, such as the number of employers posting position profiles.
- Use of profile information, such as the number of students, university faculty, employers accessing information and the amount of information accessed.
- Impact, such as the number of students whose enrollment decisions were impacted, the number of employers whose recruiting were impacted, and number of academic programs and courses changed due to information availability.

These data will be captured digitally from the website and will be analyzed on an ongoing basis, providing iterative feedback and updates to the entered profiles and website capabilities. These measures enable observation of the ecosystem's growth and evolution, as well as trends that surface through the systems engineering competency framework and competency assessments for each user group. An assessment of this success will provide the feedback necessary to update the website and determine how this approach can be applied to other disciplines.

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