ASEE 2016
INTERNATIONAL FORUM
NEW ORLEANS, LOUISIANA / JUNE 25, 2016

Paper ID #17539

The Pathway to Systems Education for the Global Engineer

Dr. Alice F Squires, Washington State University

Dr. Alice F. Squires is an Associate Professor at Washington State University (WSU) with over 30 years of technical leadership experience. Prior to joining WSU, Dr. Squires served as Manager of Systems Engineering at Aurora Flight Sciences, Senior Researcher for the nationwide University Affiliated Research Center in Systems Engineering and Online Technical Director for SSE at Stevens Institute of Technology, Senior Systems Engineer consultant to LM, IBM, and EDO Ceramics, Senior Engineering Manager at GD, Senior Engineering Manager at LM, and Advisory Engineer/Scientist at IBM. Dr. Squires is a contributing author and editor to the Systems Engineering Body of Knowledge (sebokwiki.org) and the Graduate Reference Curriculum for Systems Engineering (bkcase.org/grcse). She is certified by PMI as a Project Management Professional, and by INCOSE as a Certified Systems Engineering Practitioner, including in Acquisition. Dr. Squires is a lifetime member of the Beta Gamma Sigma, Tau Beta Pi, and Eta Kappa Nu Honor Societies. She is a Senior Member of the IEEE, a member of and Director on the Systems Engineering Division board of ASEE, and a member of the ASEM, NDIA, INCOSE, and PMI. Degrees earned include a BSEE from the University of Maryland; a MBA from George Mason University; and a Ph.D. in Systems Engineering from the Stevens Institute of Technology. Her areas of expertise include Systems Engineering, Engineering and Technical Management, Project Management, Systems Thinking, Online Education, Engineering Education, and Competency Development.

Prof. Jon Patrick Wade, Stevens Institute of Technology (School of Systems & Enterprises)

Jon Wade is a Distinguished Research Professor in the School of Systems and Enterprises at the Stevens Institute of Technology and currently serves as the Director of the Systems and Software Division and Chief Technology Officer for the Systems Engineering Research Center (SERC) where he is leading research in the use of technology in systems engineering education and complex systems. Previously, Dr. Wade was the Executive Vice President of Engineering at International Game Technology where he managed corporate wide research and development. Dr. Wade spent ten years at Sun Microsystems during which time he managed the development of Enterprise Servers. Prior to this, he led advanced development of supercomputer systems at Thinking Machines Corporation. Dr. Wade received his SB, SM, EE and PhD degrees in Electrical Engineering and Computer Science from the Massachusetts Institute of Technology.

Dr. Nicole A.C. Hutchison, Stevens Institute of Technology

Dr. Nicole Hutchison is a Research Engineer at the SERC. Her primary work through the SERC includes the Helix project. Previously she was a member of the BKCASE research team. Before joining Stevens, she spent 5 years working for Analytic Services, supporting the US Departments of Defense and Homeland Security. She holds a PhD in systems engineering from Stevens and her INCOSE CSEP.

©American Society for Engineering Education, 2016

Building a Pathway to Systems Education for the Global Engineer

Abstract
As systems become increasingly global in nature, those involved in the conception, design, development, support, sustainment, and end of life of such systems must have a global perspective on both the operational context in which those systems will be used, and the challenges faced by the development, production, deployment, and support teams involved in their creation and sustainment. To build a pathway to systems focused education, the foundations of systems knowledge and skills should be instilled in engineering students early in their education, starting with systems thinking in K-12 and building on more advanced system concepts through undergraduate education and beyond. This paper describes how societal needs combined with global trends produce systems challenges that must be addressed by engineers who are systems thinkers. After analyzing three separate undergraduate engineering education research efforts in process, the authors propose a pathway to support engineering education to mature systems engineering knowledge and skills in the engineering profession.

Introduction

Solutions to meet fundamental human needs often lead to large and complex engineered systems that can only be successful if they are socially acceptable and provide value to our global society. Yet, as humanity attempts, through engineering and technology, to make the world a better place, our ever-evolving society creates new and ever greater challenges. With these challenges in mind, the International Council on Systems Engineering (INCOSE) formed an international task force of experts in 2012 to develop the *Systems Engineering Vision 2025*[1] report on the future of systems engineering. This vision is shaped by the global environment and includes human and societal needs, policy and business challenges, and rapidly evolving technologies that serve as the foundations for developing systems. The experts found that while the systems engineering field needs to grow and thrive, this was not sufficient. The evolving work environment, following global trends, both constrains and enables the manner in which systems engineering is practiced. The multi-disciplinary perspective, critical to system product innovation, defect reduction and customer satisfaction, could no longer be the purview of only the systems engineer. The infusion of systems thinking across a broad range of the engineering and management workforce was needed to meet the demands for a growing number of systems-capable engineers with the necessary technical and leadership competencies. The experts concluded: *Leaders need to be systems thinkers; all engineers need some education and training in systems engineering knowledge and skills; and all systems engineers need to be well versed in a broad set of socio-technical and leadership skills, serving as a central, multi-disciplinary focal point for systems development with stakeholders from all walks of life.* With this as the backdrop, this paper addresses three separate research efforts focused on advancing undergraduate engineering education and integrates the findings into a proposed pathway to systems education for the global engineer.

Characteristics of Global Engineers

In 2008, the American Society of Engineering Education (ASEE) in collaboration with the International Federation of Engineering Education Societies (IFEES) formed an international team to research the attributes of the global engineer. Hundley[2] reports on the outcomes of both an "*Attributes of the Global Engineer*" survey delivered in 12 languages between October 2010

and September 2012, and a series of workshop events held from 2012 to 2015. Based on the 1,027 usable survey responses and feedback from focus groups and workshops held in the United States, Finland, Belgium, Colombia, Argentina, Japan, U.K., Spain, U.A.E., and India, twenty top attributes for global engineering effectiveness were identified and sorted into the following five categories[2]:

- ***Technical Attributes:*** Engineering-related knowledge and skills needed for disciplinary success (4 attributes)
- ***Professional Attributes:*** Workplace-related competencies needed for effective global performance (5 attributes)
- ***Personal Attributes:*** Individual characteristics needed for global flexibility (4 attributes)
- ***Interpersonal Attributes:*** Skills and perspectives needed to work on interdependent global teams (2 attributes)
- ***Cross-cultural Attributes*****:** Societal and cultural understanding needed to embrace diverse viewpoints (5 attributes)

Of these, the top eight attributes (assumed order of perceived importance) reported by Hundley[2] are shown in Table 1.

Table 1. Top Eight Attributes of the Global Engineer (adapted[2])

Category	Attributes
Professional	Communicates effectively in a variety of different ways, methods, and media (written, verbal/oral, graphic, listening, electronically, etc.)
Personal	Possesses the ability to think both critically and creatively
Personal	Shows initiative and demonstrates a willingness to learn
Interpersonal	Functions effectively on a team
Personal	Possesses the ability to think both individually and cooperatively
Technical	Demonstrates an understanding of engineering, science, and mathematics fundamentals
Technical	Demonstrates an understanding of information technology, digital competency, and information literacy
Personal	Maintains a positive self-image and possesses positive self-confidence

Of note, the collective stakeholders from the focus groups felt that the following needed to be emphasized or added to the list for engineers to be successful in the global context[3]:

- Cultural sensitivity / tolerance to other people and perspectives
- Open-mindedness and ability to adapt
- Ability to behave ethically across cultures / social responsibility
- Research, analytical thinking, problem-solving, and improvement capabilities
- Innovation and entrepreneurship

Given Cross-Cultural attributes missing from the top eight list, and the observations of the focus groups, the missing Cross-Cultural attributes, of importance to this research, are listed below[3]:

- Demonstrates an understanding of political, social, and economic perspectives
- Demonstrates an understanding of the ethical and business norms and applies norms effectively in a given context (organization, industry, country, etc.)

- Possesses an international/global perspective
- Possesses fluency in at least two languages
- Embraces an interdisciplinary/multidisciplinary perspective

Systems Engineering Expert Skills

Since 2012, the Helix team in the Systems Engineering Research Center (SERC) has been investigating what makes systems engineers effective. The team has conducted in-depth interviews with 288 individuals from 20 organizations to support this work: 263 systems engineers from a mix of the defense industry and commercial industry (healthcare, transportation, telecommunications, etc.). Validation exercises were conducted with 25 individuals who work with systems engineers (program managers, classic engineers, etc.) across a variety of organizations. Each organization participating in Helix was asked to confirm that the individuals who participated in the study were considered effective; organizational representatives assessed all individuals from "average" to "very high" effectiveness.

This data is being used to build a theory of what makes systems engineers effective, called *Atlas*, preliminary versions of which were published in 2014 and 2015.[4,5] *Atlas* includes consideration for proficiency – an individual's level of knowledge, skills, abilities, demonstration of behaviors, and cognitions – which are critical to the effectiveness of systems engineers. From the data, the Helix team has built a model of six proficiency areas, as shown in Figure 1.

The colors in Figure 1 delineate the types of proficiencies required: purple (top right pair) highlights the skills for engineering; blue (bottom pair) for engineering systems; and orange (top left pair) for working with people to engineer systems. Within each of these pairs, working clockwise the first item is an enabler for the second. For example, the fundamentals of math/science, and general engineering enable an individual to understand and build skills within the context of a specific domain and set of operational parameters. Each of the proficiencies are described briefly below[5]:

- ***Math/Science/General Engineering***, which includes the foundational concepts from mathematics, physical sciences, and general engineering required to perform basic engineering and to understand the work of other engineers.
- ***System's Domain & Operational Context***, which includes the relevant domains, disciplines, and technologies for a *given* system and its operation. This will change depending on the types of systems being developed.
- ***Systems Engineering Discipline***, which includes the foundation of systems science and systems engineering knowledge; these are the elements thought of as "traditional" systems engineering and include methods, processes, and tools.
- ***Systems Engineering Mindset***, which includes the skills, behaviors, and cognition associated with being a systems engineer, in particular the ability to view things holistically or understand multiple perspectives.
- ***Interpersonal Skills***, which are skills and behaviors associated with the ability to work effectively in a team environment and to communicate and coordinate across the problem domain and solution domain.
- ***Technical Leadership***, which includes skills and behaviors associated with the ability to create and guide a diverse team of experts toward a specific technical goal.

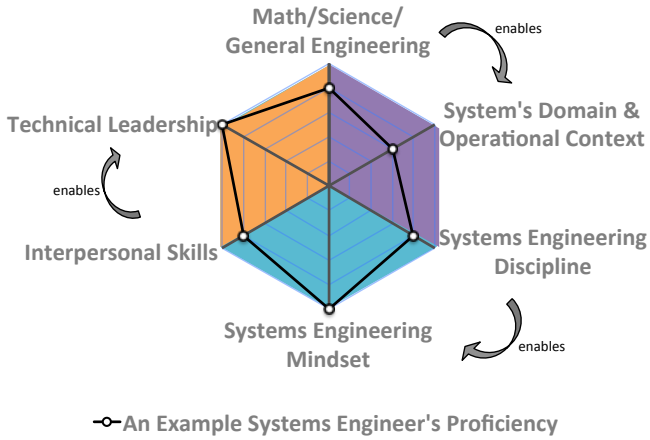

Figure 1. Helix proficiency model.

The proficiency areas that focus on working with technology – Math/Science/General Engineering, System's Domain and Operational Context, and Systems Engineering Discipline – were seen as important foundations for systems engineers to understand the systems being created and the work done by other engineers across diverse teams. However, chief systems engineers and non-systems engineers consistently cited the proficiency areas that focus on working with people – Interpersonal Skills and Technical Leadership – as areas where individuals *must* excel to be effective. Those who were skilled in the technical aspects of systems engineering only were seen as less effective and as less likely to become chief systems engineers. In terms of SE Mindset, *big-picture thinking and paradoxical mindset – the ability to simultaneously understand and hold in opposition differing views – were seen not only as critical skills, but also provided value and critical insights directly to projects*, according to the all of the non-systems engineers interviewed.

Integrating Systems Education into Undergraduate Engineering Education Workshops

In 2015, engineering and systems engineering faculty met at an International Council on Systems Engineering (INCOSE) Academic Forum in May and at the American Society of Engineering Education (ASEE) annual conference in June to discuss the need for integrating systems engineering knowledge into the education of all engineers. As part of these workshops, twenty-nine systems engineering knowledge areas of importance were identified and placed into four main categories, defined in the ASEE workshop[6] as:

1. ***Systems Science and Fundamentals:*** Formal science dealing with the nature of systems; the science "behind" systems engineering. (5 areas)
2. ***Systems Thinking:*** Holistic thinking: critical thinking guided by systems theory. (7 areas)
3. ***Design and Analysis:*** The examination of a problem from all aspects and the development of an effective solution. (10 areas)
4. ***Technical and Project Management:*** Applying knowledge, skills, tools, and techniques to manage the cost, schedule, and technical aspects of a project to meet the project requirements. (7 areas)

Between the two workshops, thirty-six faculty members participated through a voting scheme to determine the top system knowledge differentiators in undergraduate engineering education listed in Table 2. Each differentiator listed received from 3 to 30 votes. Using the final vote counts for the top 13 differentiators, relative importance is shown in the % column.

Table 2. Results of Voting – Top 13 System Knowledge Differentiators (adapted[6])

Categories	System Knowledge Differentiators	%
Systems Thinking	Interdependencies (interactions, interfaces, relationships) among multi-disciplines	28%
Systems Thinking	Problem Analysis (goals and objectives, needs statement, requirements elicitation)	12%
Design and Analysis	System Modeling	8%
Design and Analysis	Trade off and Decision Analysis	8%
Design and Analysis	Requirements Analysis	8%
Systems Science	Understanding Complexity	8%
Design and Analysis	Systems Architecture and Analysis	6%
Design and Analysis	Systems Integration	5%
Systems Thinking	Total Life-cycle View	5%
Systems Science	Systems Theory	4%
Technical and Project Management	Dealing with Uncertainties and Change	4%
Systems Science	Emergence	3%
Systems Thinking	Multiple and holistic perspectives	3%

Proposed Pathway to Systems Education for the Global Engineer

To build a pathway, first the previous research outcomes, shown in Table 3 by research area, are integrated into a set of categories, which capture the essence of the findings.

Table 3. Consolidation of Findings from Mutually Exclusive Research Teams

Thinking/Mindset Approaches	
Global Engineer	Possesses the ability to think both critically and creatively; and individually and cooperatively
SE Expert	Systems Engineering mindset; Ability to view things holistically
Integrating SE	Interdependencies (interactions, interfaces, relationships) among multi-disciplines; Problem Analysis (goals and objectives, needs statement, requirements elicitation)
Multiple Perspectives	
Global Engineer	Possesses an international/global perspective; Demonstrates an understanding of political, social, and economic perspectives; Embraces an interdisciplinary/multidisciplinary perspective
SE Expert	Systems Engineering mindset; Ability to understand multiple perspectives
Integrating SE	Total Life-cycle View; Multiple and holistic perspectives
Understanding Context	
Global Engineer	Demonstrates an understanding of the ethical and business norms and applies norms effectively in a given context (organization, industry, country, etc.)
SE Expert	Understands system's domain and operational context including relevant domains, disciplines, and technologies for a given system and its operation.
Integrating SE	Understanding Complexity; Systems Theory; Emergence

Foundational Technical Skills	
Global Engineer	Demonstrates an understanding of engineering, science, and mathematics fundamentals; Demonstrates an understanding of information technology, digital competency, and information literacy
SE Expert	Understands foundational concepts from mathematics, physical sciences, and general engineering required to perform basic engineering; Understands the work of other engineers; Understands the foundation of systems science and systems engineering knowledge, including methods, processes, and tools.
Integrating SE	System Modeling; Trade off and Decision Analysis; Requirements Analysis; Systems Architecture and Analysis; Systems Integration
Personal/Interpersonal Skills	
Global Engineer	Communicates effectively; different ways, methods, and media (written, verbal/oral, graphic, listening, electronically, etc.); Shows initiative and demonstrates a willingness to learn; Functions effectively on a team; Maintains a positive self-image and possesses positive self-confidence; Possesses fluency in at least two languages
SE Expert	Has ability to work effectively in a team environment and to communicate and coordinate across the problem domain and solution domain; Includes skills and behaviors associated with the ability to create and guide a diverse team of experts toward a specific technical goal.
Integrating SE	Dealing with Uncertainties and Change

Next, a proposed pathway to support the maturation of the global engineer of 2025 and beyond was developed using the same categories from Table 3 and additional background research on building system concepts starting in Kindergarten. The approach is applied over the lifelong education pathway of the global engineer and is presented in Table 4.

Table 4. Proposed Pathway to Systems Education for the Global Engineer (Thinking/Perspectives/Context adapted[7])

Early Years: 5 - 10 years	*Thinking/Mindset Approaches*	Understands linear cause and effect; recognizes simple patterns.
	Multiple Perspectives	Understands simple concepts (e.g. sharing) from another person's viewpoint; identifies internal feedback related to simple continuous processes in one's own daily events.
	Understanding Context	Recognizes relationships of parts with a context (e.g. member of a family); distinguishes internal from external feedback.
	Foundational Technical Skills	*Follow STEM guidelines.*
	Personal/Interpersonal Skills	Exposed to group work; begins second language; uses more than one media for written and verbal communication.

Middle Years: 11 - 13 years	*Thinking/Mindset Approaches*	Recognizes simple non-linear causal relationships with real-world variables; graphs behavior over time; understands and uses causal loop diagrams and system archetypes; identifies system goals and develops more complex pattern recognition.
	Multiple Perspectives	Runs and analyzes case studies; identifies states and state changes.
	Understanding Context	Recognizes and defines context; relates impact of changes in environment to change in familiar behaviors.
	Foundational Technical Skills	*Follow STEM guidelines.*
	Personal/Interpersonal Skills	Continues group work; achieves elementary level of second language; uses multiple media for written and verbal communication.
Teenage Years: 14 – 17 years	*Thinking/Mindset Approaches*	Recognizes system archetypes; generates system models and deduces system behaviors.
	Multiple Perspectives	Creates system models with internal and external feedback and with multiple states and state changes.
	Understanding Context	Rigorously analyzes and tests system models for robustness (level of insensitivity to changes in environment/context).
	Foundational Technical Skills	*Follow STEM guidelines.*
	Personal/Interpersonal Skills	Understands importance of communicating effectively across multiple media; participates in positive team experiences; achieves middle school level of second language; achieves success in most subjects due to developed intrinsic motivation to learn.
Young Adult: 18 – 21 years	*Thinking/Mindset Approaches*	Understands more than one discipline in sufficient depth to apply a multidisciplinary approach to system model development with accurate modeling of interactions, interfaces, and relationships; reliably predicts system behaviors when changes are made.
	Multiple Perspectives	Integrates a total life cycle view and multiple perspectives into design approaches; able to optimize solutions to address the right problem, factoring in both development and operational considerations.
	Understanding Context	Applies systems theory concepts including complexity and emergence into system modeling and analysis.
	Foundational Technical Skills	Achieves application level of: system modeling; trade off and decision analysis; requirements analysis; systems architecture and analysis; and systems integration.

	Personal/Interpersonal Skills	Achieves application level for communicating effectively across multiple media and team effectiveness and in two or more languages; values lifelong learning; possesses self-confidence and positive self-image; effectively deals with uncertainty and change.
Adult: > 21 years	*Achieves Knowledge and Skills listed in Table 3.*	

Conclusion

As the community comes together to mature the building of the pathway to systems education for the global engineer, the principles that we believe are critical for success in the undergraduate systems education of global engineers focus on individualized, agile, experiential, and learner centric processes where multiple disciplines are integrated in a setting that recreates the practicing environment. Our pathway to developing a global engineer starts with systems thinking concepts being introduced alongside the traditional reductionist and critical thinking approaches found in our standards today, and continues through the pursuit of lifelong learning.

Acknowledgements

The authors wish to thank several teams for the foundational contributions to this work. These teams include the ASEE Attributes of the Global Engineer team, the INCOSE Vision 2025 team, the Systems Engineering Research Center (SERC) Helix team, and the INCOSE Academic Forum team.

References

1. Friedenthal, S., Beihoff, B., Nichols, D., Oster, C., Paredis, C., Stoewer, H, Wade, J. (2014, October), A World in Motion: Systems Engineering Vision 2025, International Council on Systems Engineering, http://www.incose.org/docs/default-source/aboutse/se-vision-2025.pdf?sfvrsn=4
2. Hundley, S. (2015a, June), The Attributes of a Global Engineer: Results and Recommendations from a Multi-Year Project Paper presented at 2015 ASEE International Forum, Seattle, Washington. https://peer.asee.org/17160
3. Hundley, S. (2015b, June), The Attributes of a Global Engineer Summary presented to the Corporate Member Council at the ASEE 2015 Annual Conference and Exposition, Seattle, Washington.
4. Pyster, A., P. Dominick, D. Henry, N. Hutchison, C. Lipizzi, M. Kamil, S. Manchanda. 2014. Atlas*: The Theory of Effective Systems Engineers, version 0.25*. Hoboken, NJ: Stevens Institute of Technology. SERC-2014-TR-038-4. November 21, 2014.
5. Pyster, A., D. Henry, N. Hutchison, C. Jauregui, M. Clifford. 2015. Atlas: *The Theory of Effective Systems Engineers, version 0.5*. Hoboken, NJ: Stevens Institute of Technology. SERC-2015-TR-108. December 1, 2015, http://www.sercuarc.org/wp-content/uploads/2014/05/Helix-Report-Atlas-0.5-December-2015.pdf
6. Squires, A., Looft, F., Virani, S.S. (2015), "Integrating Systems Education into Undergraduate Engineering Education plus INCOSE Spring Academic Forum Summary Workshop Report", Report of Workshop delivered at the 2015 American Society for Engineering Education (ASEE) Annual Conference and Exposition, Seattle, Washington, June 14, 2015.
7. Squires, A., 2007, *Systems Thinking and K12 Education*, Doctoral Qualifying Examination, Stevens Institute of Technology, School of Systems and Enterprises, November 21, 2007.