Undergraduate Systems Engineering Programs in the US

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13th Annual NDIA Systems Engineering Conference
San Diego, CA | October 27, 2010

"A capable, qualified, and appropriately sized acquisition workforce will be key to achieving efficiency."

-- Dr. Ashton Carter
Under Secretary of Defense
for Acquisition Technology and Logistics

Better Buying Power: Guidance for Obtaining
Greater Efficiency and Productivity
in Defense Spending (14 Sep 2010)

What Does the DoD Expect from its Systems Engineering Workforce?

- **Breadth**
  - Awareness of and appreciation for other functional areas,
  - Understanding of the system lifecycle and processes
  - Knowledge of other engineering disciplines and how they integrate into the system solution
  - Knowledge of product domains

- **Depth**
  - Extensive expertise and experience in one or more engineering disciplines and in one or more product domains

- **Leadership**
  - Ability to motivate and inspire individuals and teams
  - Comfort in dealing with complexity
  - Focused on underpinning decisions with data
  - Capability to make tough technical decisions

Motivation

Because the DoD needs many capable systems engineers, it is important to understand the size, focus, success, and challenges of undergraduate SE programs and help improve the impact of those programs.

This Presentation Covers…

- Historical trends in US undergraduate Systems Engineering (SE) programs

- Results of a workshop held in April 2010 on US undergraduate SE programs – including recommendations

First a History Lesson…

- ***Historical trends in US undergraduate systems engineering (SE) programs***

- Results of a workshop held in April 2010 on US undergraduate SE programs – including recommendations

Program Population Growth

There is healthy growth in the number of U.S. systems engineering programs at both the undergraduate and graduate levels

1999: 29 schools offered 58 programs at undergraduate and graduate levels – *19 undergraduate programs*

2004: 75 schools offered 130 programs at undergraduate and graduate levels – *43 undergraduate programs*

2009: 80 schools offered 165 programs at undergraduate and graduate levels – *55 undergraduate program*

Brown, D. E. & Scherer, W. T. (2000). A comparison of Systems Engineering Programs in the United States. Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on, 30(2), 204-212.

Fabrycky, W. J. and McCrae, E.A. (2005). Systems Engineering Degree Programs in the United States", in Proceedings of the 15th Annual International Symposium, INCOSE 2005, Rochester, NY, July, 2005 .

Fabrycky, W.J., "Systems Engineering: Its Emerging Academic and Professional Attributes", Proceedings of the 2010 American Society for Engineering Education Conference and Exposition, Lexington, KY, June 20-23, 2010.

Two Broad Types of Programs

- <u>Systems-Centric</u>: where the concentration is designated as SE; where SE is the intended major area

- <u>Domain-Centric</u>: SE education and training that integrates the best SE practices within the traditional engineering disciplines… SE with biological engineering, SE with industrial engineering, etc.

Useful, but not a perfect distinction – some programs have characteristics of both; e.g., Stevens has a master's of SE (SCSE), but offers a certificate in Space Systems SE (DCSE). Also, some programs integrate significant SE without using "systems engineering" in the name of their degree.

* Fabrycky, W.J., "Systems Engineering: Its Emerging Academic and Professional Attributes", Proceedings of the 2010 American Society for Engineering Education Conference and Exposition, Lexington, KY, June 20-23, 2010.

2009 Program Distribution by Type

Type	B	M	PhD	Total
Systems Centric SE	11	31	14	56
Domain Centric SE w/ Biological Engineering	18	10	6	34
Domain Centric SE w/ Computer Engineering	7	5	3	15
Domain Centric SE w/ Industrial Engineering	17	17	13	47
Domain Centric SE w/ Management Engineering	1	2	0	3
Domain Centric SE w/ Manufacturing Engineering	1	8	1	10
Total	*55*	*73*	*37*	*165*

Parsing XX Systems Engineering important. Some programs are more about (XX Systems) Engineering rather than XX (Systems Engineering) – *more on this later…*

10-Year Trend

Type of SE Program	Degree Level	Brown & Scherer (2000)	Fabrycky (2010)	Increase Factor
Systems Centric	Bachelors	10	11	1.1
	Masters	10	31	3.1
	Doctorate	3	14	4.7
	Systems Centric	23	56	2.4
Domain Centric	Bachelors	9	44	4.9
	Masters	17	42	2.5
	Doctorate	9	23	2.6
	Domain Centric	35	109	3.1
All	Bachelors	19	55	2.9
	Masters	27	73	2.7
	Doctorate	12	37	3.1
All	All Degrees	58	165	2.8

Reference: Squires, A. (2010) DRAFT: Measuring the Value of Remote Online Systems Engineering Education, PhD Dissertation, Stevens Institute of Technology

Program Growth is Not Uniform

- Over last decade, strong growth for some:

  - Undergraduate DCSE grew from 9 to 44 programs (~5x)

  - Graduate SCSE grew from 13 to 45 programs (~3.5x)

- Least growth in undergraduate SCSE programs
  - from 10 to 11

- Overall growth is close to 3x, but has slowed significantly in the last 5 years

Why The Disparity in Growth?

- This disparity may reflect the belief by many that SE is inherently experiential-based.

- Perhaps undergraduates, who largely lack experience, best learn SE in the context of another engineering discipline/application domain (DCSE) rather than as a "pure" SCSE.

- Perhaps graduates, who often enter a program with substantial industrial experience, can succeed in either a DCSE or a SCSE program.

And Now The Workshop…

- Historical trends in US undergraduate systems engineering (SE) programs

- ***Results of a workshop held in April 2010 on US undergraduate SE programs – including recommendations***

http://www.acq.osd.mil/se/docs/Undergraduate-Systems-Engineering-Program-Workshop-Report-Final.pdf

1st Undergraduate SE Workshop

Purpose: Examine the state of US undergraduate SE programs

Attendees: More than 60 professionals from academia, government, and industry

Venue: US Air Force Academy on April 7-8, 2010

Three goals:

➢ Explore the characteristics, successes, and challenges of US bachelor's degree programs in SE.

➢ Build a sense of community among US faculty who provide undergraduate SE programs.

➢ Develop high-level proposals for how to reinforce the strengths of those programs and address their challenges, thus increasing their value to students and prospective employers in a practical way.

Keynote Addresses

- *Department's Need for Young Systems Engineers*
  by Steve Welby, Director, SE, ODDR&E

- *Developing Our Systems Engineers*
  by Charles Toups, VP/GM Network
  and Tactical Systems, Boeing

- *US Air Force Academy Systems Engineering*
  by Lt Col Paul Lambertson, Director, SE

- *BKCASE Project and an Analysis of US Undergraduate Programs in SE*
  by Art Pyster, Stevens Institute of Technology

Panel Sessions

1. *What are Best Practices in Teaching SE to Undergraduates?*

   Panelists: Michael Smith, Drew Hamilton, Seshadri Mohan, Armen Zakarian

2. *Should SE Degrees Only Be Offered at The Graduate Level?*

   Panelists: Dinesh Verma, Dennis Barnabe, Thomas Mazzuchi, Timothy Trainor, Brian Wells

3. *How Much Classical Engineering and Domain Focus Should Be in a Bachelor's Degree in SE?*

   Panelists: Don Taylor, Paul Coffman, Brian Gallagher, Brett Peters, Ariela Sofer

Breakout Sessions

1. What are the primary undergraduate education requirements for SE personnel in government program offices?

2. What are the top 5 challenges to successful bachelor's degree programs in SE and how should those challenges be addressed?

3. Within the first four years after graduation, what should someone with a bachelor's degree in SE know and be capable of doing on the job?

4. How much classical engineering (general, industrial, mechanical, electrical, etc.) and application domain focus (telecommunications, naval, medical, etc.) should be in a bachelor's degree in SE?

State of the US

1. Strong Demand

2. Distinction Lessens Over Time

3. Real Engineers

4. Systems vs. Domain Centric

5. Distinction Is Fuzzy

6. Industrial vs. Systems Engineering

7. Top 4 Challenges

8. Program Offices Are No Different

Strong Demand

- Both industry and government have a strong demand for trained, experienced systems engineers

- Prefer those who can:

  - think holistically about complex problems

  - are comfortable with the increasing complexity of systems that address those problems

  - can manage the uncertainty and complexity of the environment in which those systems are being built

  - can respond to demands to shorten the time to deliver systems to the field

Strong Demand - Recommendation

Conduct research to understand the demand in both the defense community and the broad U.S. economy for graduates of undergraduate systems engineering programs

Distinction Lessens Over Time

- Companies routinely hire engineers with bachelor's degrees in disciplines other than SE and develop them into systems engineers

- They hire engineers with bachelor's degrees in SE, but in far fewer numbers

- New hires are apprentices, not journeymen or experts.

- During first 2 years after graduation, distinction between SE and non-SE degree is sharpest

- After 4 years of work experience, there is little distinction between engineers who learn SE on the job and those who first learn it as an undergraduate

Conduct research to understand the jobs that graduates with a bachelor's degree in SE hold during their apprenticeship period, to understand the competencies valued most by employers during that period, and to understand the relative performance of those with an SE degree and those with an engineering degree other than SE

Real Engineers

- Undergraduate SE programs generally produce "real" engineers

- Programs are Accreditation Board for Engineering and Technology (ABET) accredited

- Curricula incorporate classical engineering courses in physics, circuits, mathematics, mechanics, chemistry, etc.

- Graduates of these programs generally are prepared to sit for the Fundamentals of Engineering Exam required in most states to become certified as Engineers in Training

Real Engineers - Recommendation

Conduct research to understand how many graduates of SE programs go on to become certified Engineers in Training and eventually certified Professional Engineers. Determine why graduates seek or forgo certification

Systems vs. Domain Centric

- There are dozens of undergraduate programs that include the phrase "systems engineering" in their titles.

- All but 11 do so in combination with other disciplines

- No study has looked in detail at what is being taught in the Domain Centric SE programs to understand the balance between SE and the domain in the programs.

Systems vs. Domain Centric - Recommendation

Conduct additional research to understand what SE is being taught in Domain Centric SE programs and where the graduates are being employed

Distinction is Fuzzy

- Distinction between Systems Centric and Domain Centric SE programs is not as sharp as the names imply.

- Systems Centric programs generally require students to specialize in an application area such as finance, or in an additional discipline such as electrical engineering.

- The effect is that the Systems Centric programs are often a hybrid of a "pure" program in systems engineering and a Domain Centric program.

Distinction is Fuzzy - Recommendation

Hold a workshop to sharpen the understanding of the similarities and differences between Systems Centric and Domain Centric SE programs

Industrial vs. Systems Engineering

- Distinction between Industrial Engineering (IE) and SE is unclear.

- I&SE Department website at Texas A&M states "Industrial engineers deal with **systems**. They can design, implement or improve integrated systems comprised of people, materials, information or energy."

- Similar to SE & OR Department website at GMU - "Systems Engineers determine…most effective ways …to use all of a given system's components -- people, machines, materials, information, and energy. Systems engineers plan, design, implement and manage complex systems that assure performance, safety, reliability, ..."

Hold a workshop to sharpen the understanding of the similarities and differences between Industrial Engineering and SE

Top Four Challenges

- Understanding and meeting customers needs within curriculum constraints,

- Sustaining technical and societal relevance

- Incorporating sufficient real-world problem solving into the curriculum

- Identity-communications-community of practice

Hold a workshop to elaborate more fully on these challenges and develop a sharper roadmap to address them

Program Offices Are No Different

- Undergraduate educational requirements for systems engineers who will work in U.S. government program offices are quite similar to those who graduate from a "typical" Systems Centric SE program

- For example, graduates should first be an engineer, then be a systems engineer

- They should be educated in systems analysis, requirements management, life cycle choices, trade-off analysis, and other concepts typically taught in Systems Centric SE programs

2nd Undergraduate SE Workshop

- Up to 100 people

- Add more industrial participation outside the defense/aerospace sectors and adding more representation from DoD program offices and product center chief engineers

- Directly address one or more earlier recommendations
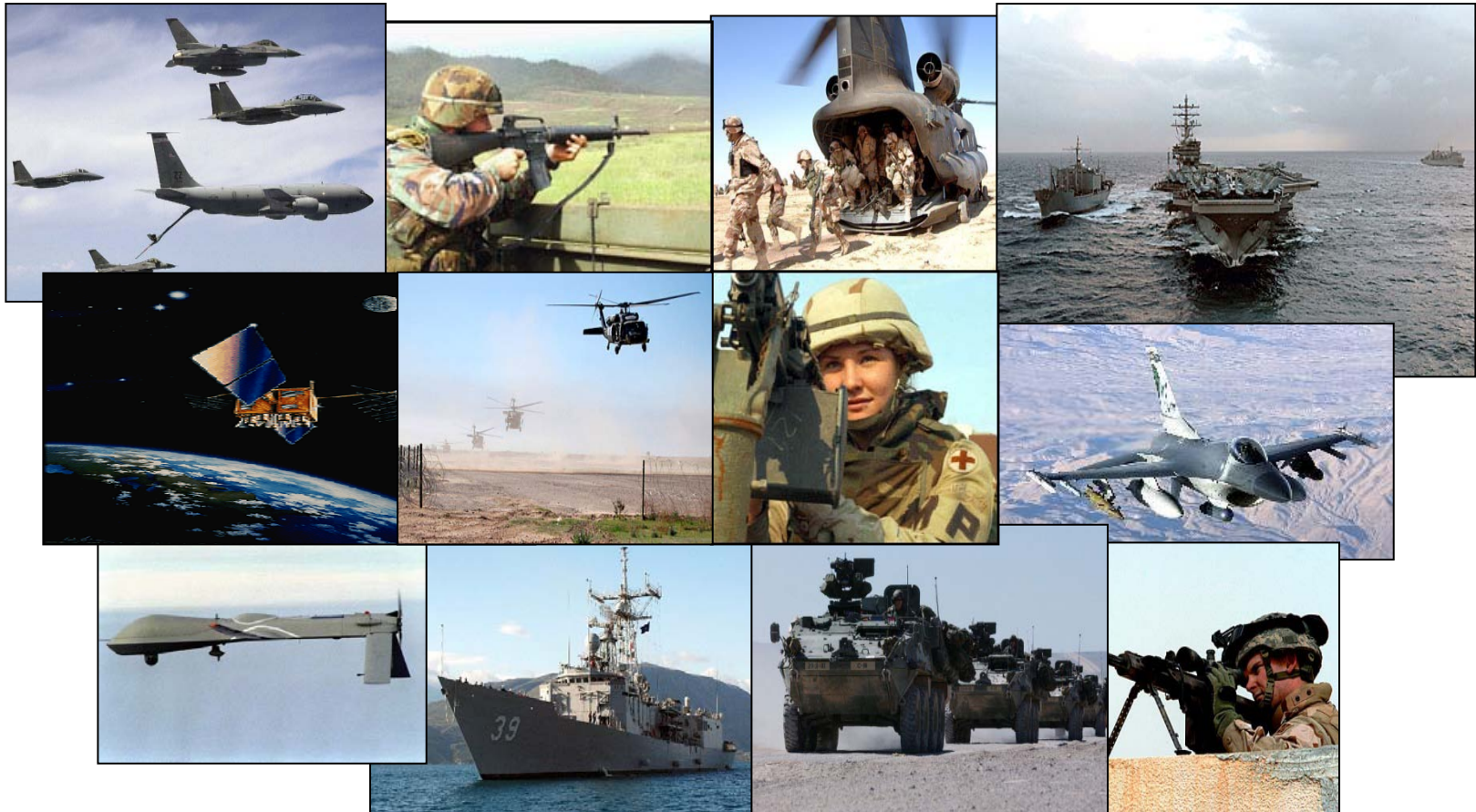
For Additional Information

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Systems Engineering:
Critical to Program Success

Innovation, Speed, and Agility
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