

Aligning Computing Education with Engineering Workforce Needs

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The Argument for Integrating Engineering Education and Workforce Skills

Industries and educational institutions across the country are experiencing huge workforce and economic challenges posed by a global economy. Skill requirements of jobs at all levels are changing rapidly, particularly in the science, technology, engineering, and math (STEM) disciplines. This often translates into a need for advanced knowledge in a single science, engineering, or math discipline, knowledge in a computational discipline, and the ability to apply new technologies to solve problems. Emerging industry sectors in the renewable energy area are further amplifying the need for individuals educated in the STEM disciplines. These rapid workforce and economic changes present new challenges to job seekers, employers, educators, and workforce and economic development professionals.

During an interview with the American Council of Engineering Companies (ACEC) in December 2008, President-elect Obama vowed “to strengthen STEM education” through the creation and implementation of a comprehensive education plan. This plan involves the introduction of legislation to support a strong STEM workforce through the creation of a scholarship to encourage students to get into STEM careers. The legislation includes an amendment to the America COMPETES Act, the bolstering of the STEM teaching profession through the Teacher Service Scholarships, and the \$4,000 American Opportunity Tax Credit.¹

Despite the growing need for higher level STEM skills, school-to-work programs are often focused primarily on K-12 curriculum reform, with little attention given to post secondary education. For example, the Council for Excellence in Government held a series of town meetings in 2004-2005 on the future of American jobs. While high quality public schools were identified as critical to job creation and economic development, only 28% of the participants prioritized the need for the private sector to work with colleges and universities to improve the transition from school to work.²

In response to these economic conditions and computational skill needs, a two-year project was funded by the National Science Foundation (NSF) in the summer of 2007 called A Collaborative Process to Align Computing Education (CPACE) with Engineering Workforce Needs

(<http://cpace.egr.msu.edu>). CPACE is a community building project that is also part of broader regional collaborative efforts to transform Michigan’s economy and workforce. These regional efforts include work being done by the Mid-Michigan Innovation Team (MMIT), which is a network of community leaders overseeing mid-Michigan’s U.S. Department of Labor’s WIRED initiative. MMIT, sponsored by the Prima Civitas Foundation, specifically seeks to transform the region’s largely traditional manufacturing-based economy by fostering innovation, talent development (particularly in the STEM area), and collaboration.

The CPACE project brings together Michigan State University (MSU) (<http://www.msu.edu>) in partnership with Lansing Community College (LCC) (<http://www.lcc.edu>) and the Corporation for a Skilled Workforce (CSW) (<http://www.skilledwork.org>), in a process to transform undergraduate computing education within engineering and technology fields. Other key partners that have informed the direction of this project include the CPACE Advisory Board (consists of members from business, government, and education), and Western Michigan University’s Science and Mathematics Program Improvement (SAMPI) division (<http://www.wmich.edu/sampi/>).

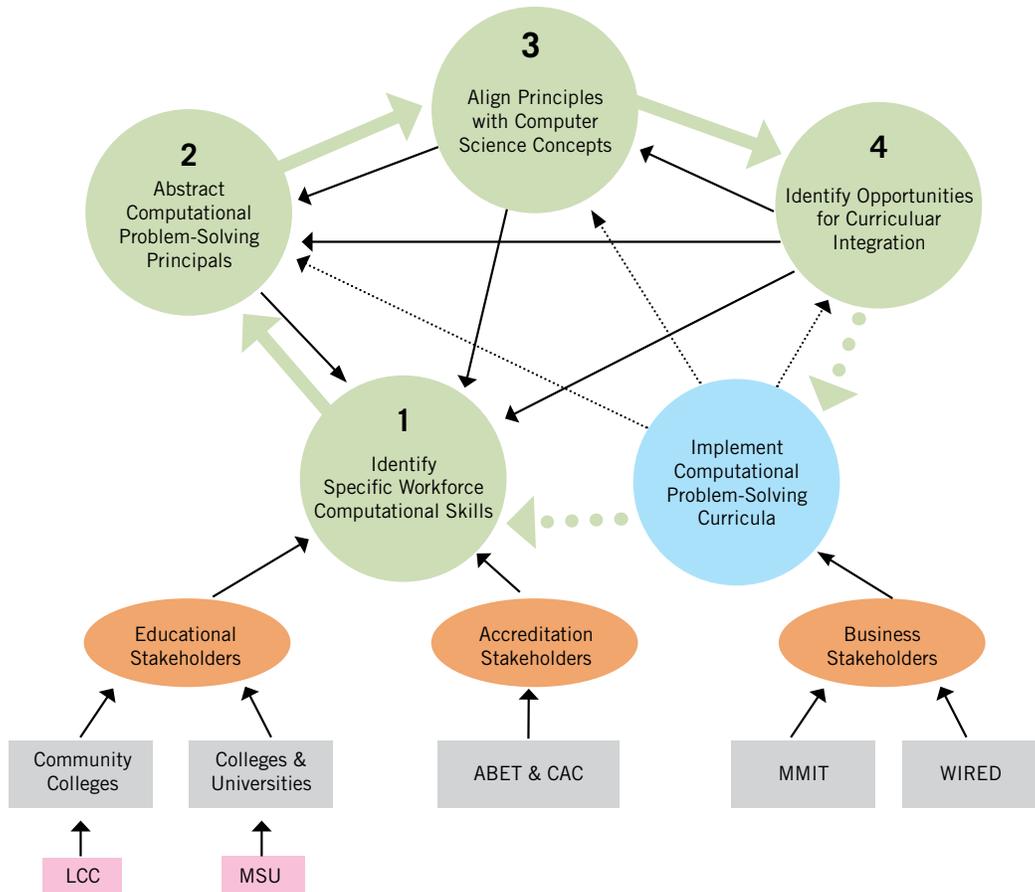
This transformational collaborative process (depicted in Figure 1) is intended to bring together a wide variety of stakeholders—business, community leaders and post

1 ACEC, December 2008, pp. 14

2 Goldman Sachs, 2006, pp. 11 - 13

Figure 1. CPACE Transformation Model

The model provides a framework that allows all stakeholders to view their needs in the context of the entire process. The primary focus of this project is on the nodes that are highlighted in green. The various stakeholders groups and subgroups involved in the Identify Specific Workforce Computational Skills node are highlighted in orange. The thick arrows connect the nodes leading to Identify Opportunities for Curricular Integration. This model envisions a cyclic process with feedback among the five major nodes. The blue node indicates the curricular implementation process that will be addressed in a subsequent proposal.



secondary educators—to identify the computational knowledge and skills that are essential for an engineering workforce in the 21st Century. By computational knowledge and skills, we are referring to how the engineering workforce uses computers to help analyze, design, model, and make decisions.

The activities involved in the implementation of this process include identifying workforce computational skills through interviews and surveys, abstracting computational principles represented by the workforce skills, defining how these skills can be integrated across a curriculum, and developing redesigned curricula that integrates computational problem-solving with engineering courses. By documenting, evaluating, and making each step explicit, this process can ultimately serve as a model for national

efforts to revitalize undergraduate computing education in engineering, and should be extensible to other computing education reform efforts.

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The Report

The research presented here is intended to provide foundational data for revising the curricula across engineering departments at Michigan State University and Lansing Community College. The data will help inform the incorporation of computational problem-solving tools within various engineering disciplinary contexts. By making these curricula enhancements, engineering graduates will enter the workforce with improved and practice-ready computational thinking. According to Jeannette Wing, computational thinking “represents a universally applicable attitude and skill set” fundamental for everyone.³ Broadly defined, computational thinking involves solving problems and designing systems by drawing on fundamental computer science concepts. It is a vital component in the preparation of engineering students who will be able to meet the challenges of this global economy.

The long-term goal of this effort is to increase communication between academic institutions and employers that will lead to better education for employees and greater information sharing and knowledge brokering. We hope that these efforts will lead to employees better prepared in the areas of computational problem-solving, independent thinking, creativity, and innovation.

In this report we discuss the skill needs of engineering employers and employees within the context of demographics, talent demand, engineering work changes, talent expectations, and talent recruitment. We will discuss the implications of these results on current and future engineering practices, and foreshadow how these data is intended to be used over time to inform engineering curricula change at Michigan State University and Lansing Community College. We will also discuss how we will sustain and strengthen the educational-employer partnerships that have been established as a result of this collaborative endeavor.

This subject matter in this report is intended to serve as feedback to the businesses that participated in the study as well as provide information to other businesses, industry groups, and the public at large. The names of businesses and their identifiable product/service lines have been described generically throughout this report and will remain confidential.

THE DATA COLLECTION FRAMEWORK & CHARACTERISTICS

To identify workforce computational skills, the CPACE research team conducted interviews with 28 small to large public and private employers across various industries within Michigan and surveyed 181 employees working in these companies. By design, the cohort of companies with whom we worked differed in a number of ways, including employee size, industry representation, and products and services offered. However, all of the companies consider engineers as critical to their core business and therefore regard engineering as a major talent driver.

To identify entry-level engineering occupations and industries for targeted research, the research team analyzed industry and occupational data drawn from the U.S. Bureau of Labor Statistics (BLS) Occupational Classifications (i.e., Upper Mid-West and National levels) and the O*NET program, which is the U.S. Department of Labor’s primary national source of occupational information to select target companies and employees.

Those occupations included civil engineers, computer hardware engineers, electrical engineers, chemical engineers, mechanical engineers, civil engineering technicians, electrical engineering technicians, mechanical engineering technicians, manufacturing engineering technicians, and industrial manufacturing technicians. The industries

3 Jeannette Wing: *Computational Thinking*, *Communications of the ACM*, March 2006/Vol. 49, No. 3, p 33

targeted included architectural and engineering services, local government, electronic instrument manufacturing, state government, motor vehicle parts manufacturing, scientific research and development services, semiconductor and electronic component manufacturing, general purpose machinery manufacturing, computer systems design; and power generation and supply.

These occupations and industries combined represented the following key Michigan State University and Lansing Community College engineering disciplines: Applied engineering sciences; Bio-systems engineering; Chemical engineering; Civil engineering; Computer engineering; Electrical engineering; Mechanical engineering; civil engineering technology/technician; Electrical/electronics/communications engineering technology/technician; Industrial production technologies/technicians; Mechanical engineering/mechanical technology/technicians; and Computer technology/Computer systems technology.

Size. We interviewed 28 companies with operations primarily in Michigan, with the exception of one large company that recruits staff in Michigan. Some companies

had operations only in Michigan while others were large multi-nationals with operations throughout the world. In almost every case, the companies' market reach was national or international.

- 8 were Huge (7,000 or more full time employees)
- 6 were Large (1,000 to 6,999 full time employees)
- 8 were Medium (200 to 999 full time employees)
- 6 were Small (1-199 full time employees)

Given the range of company sizes in the sample, it is not surprising that the number of engineers within these companies varied widely as well. Some firms have fewer than five engineers on staff while others have thousands. There was also a wide variety of types of engineering technicians employed.

Employee occupational characteristics. Due to the unprecedented economic challenges being experienced at the time of our research, some of the employers in the motor vehicles industry sector asked that their employees not participate in the survey process due to low morale as a result of the high levels of company layoffs. The employee survey response rate was also affected by newly established policies

Table 1. Occupational Representation, National U.S. Bureau of Labor Statistics

Engineering Occupational Discipline	Upper Mid-West Occupational %	National Occupational %	CPACE Occupational %
Agricultural / Biological / Bio-systems Engineering	-	-	2
Chemical Engineering	2	3	10
Civil Engineering	18	22	45
Computer Engineering	4	7	1
Electrical/Electronics Engineering	22	25	10
Environmental Engineering	-	-	1
Materials Engineering	-	-	1
Mechanical Engineering	30	19	16
Other, please specify	-	-	1
Industrial Engineering	-	-	1
Mechanical Tech	6	4	5
Civil Tech	6	8	7
Electrical Tech	12	14	1

at a couple of large companies that prevented employee engagement in non-company sponsored survey activities.

Despite our employee survey participation challenges, our employee survey sample proved to be representative of the upper mid-west (i.e., Michigan, Ohio, Illinois, Indiana, Minnesota, and Wisconsin) and national labor market occupational data drawn from the National U.S. Bureau of Labor Statistics, except in a few instances depicted in Table 1. For example, the chemical engineering and civil engineering representation in our sample was higher than the upper mid-west and national occupational data. As a result of the economic challenges in the manufacturing vehicle industry sector mentioned previously, the CPACE mechanical engineering sample representation was a bit lower than anticipated compared to the upper mid-west occupational data, but 3% higher than the national occupational representation.

Industry Representation. Since companies could indicate representation in more than one industry, a wide range of industries emerged (see Figure 2). The top three were:

- Alternative Energy
- Automotive
- Mechanical

Additional common sectors were:

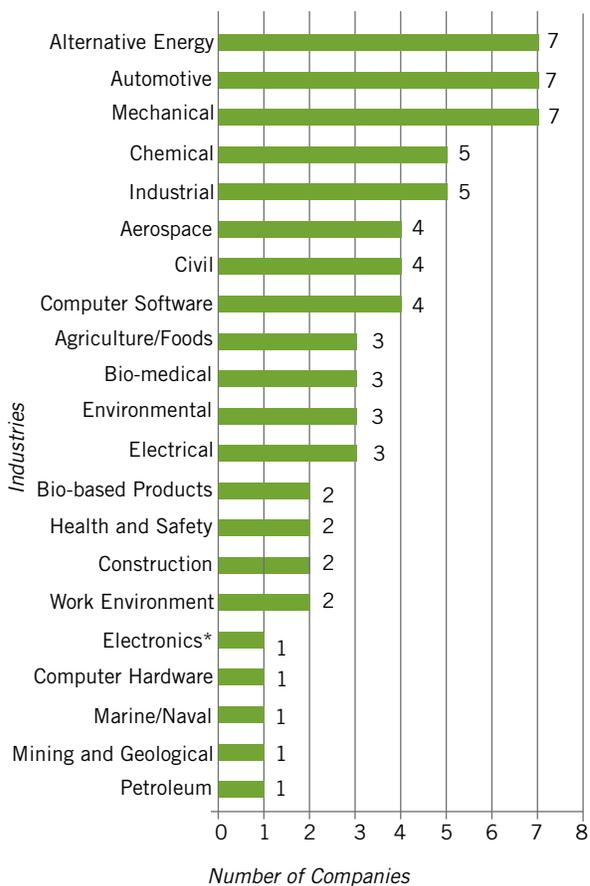
- Chemical
- Industrial
- Civil
- Biomedical
- Agriculture/Foods
- Aerospace

Other sectors such as environmental, computer software, naval and mining and geological were also mentioned.

EMPLOYEE DEMOGRAPHIC INFORMATION

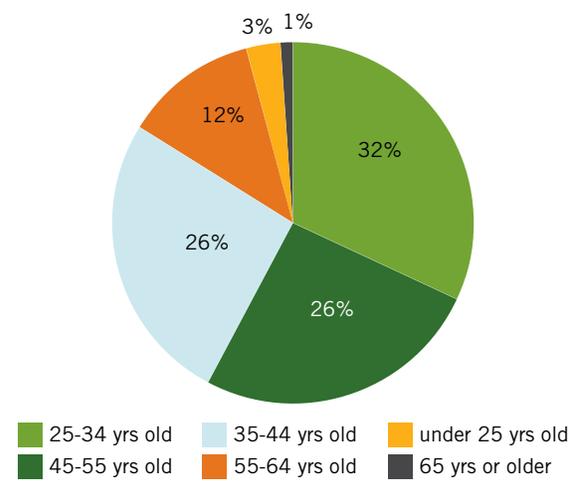
The demographics of employees in our survey varied widely. The most significant variation occurred across age. Over one third of sampled employees were under 35 years old, meaning their undergraduate experience had likely occurred within the last 10-15 years. Half of the sample was in mid-career, while a small portion was over 55. See Figure 3.

Figure 2. Industry Representation



*Except Computer

Figure 3. Employee Demographic Distribution of Age (Men & Women Combined)



Gender and racial diversity was similar to national trends in engineering—mostly male and mostly white. Note, however, that most women in our sample were age 25-34, reflecting more women entering and staying in engineering over the last 30 years (Table 2). All but one of the women in the sample was white.

Interestingly, racial diversity in our sample did not reflect this gender age pattern. Only two engineers under age 35 were not white; overall, 89% of the sample was white. Hispanics were represented at 3% and Asians at 1%.

Non-whites were represented pretty equally in age groups 35-44 and 45-55.

Not surprisingly for this profession, over 40% of the sample had schooling beyond a bachelor’s degree. Our sample contained a large portion of engineers between ages 35-55; additional schooling for this age cohort is not unusual. Because we wanted to survey engineering technicians as well as engineers, about 10% of the sample had associates’ degrees or vocational school training. ■

Table 2. Employee Demographic Distribution of Age, Separated by Males & Females

Age	Males	% of Males	Females	% of Females	Total	% of Total
25-34 yrs old	44	30	15	45	59	33
45-55 yrs old	39	26	8	24	47	26
35-44 yrs old	40	27	7	21	47	26
55-64 yrs old	19	13	2	6	21	12
under 25 yrs	5	3	0	0	5	3
65 yrs or older	1	1	1	3	2	1
Total	148	-	33	-	181	-

Skill Needs

As mentioned earlier, the overall purpose of the CPACE project is to identify engineering workforce computational skills (primarily outside the computer science discipline) through interviews and surveys with employers and employees that will inform curricular change that integrates computational problem-solving across engineering courses.

The CPACE research team analyzed the data to identify key findings that reflect the state of engineering today and the talent pipeline. The findings fall into the major areas of:

- Talent demand
- Changing nature of engineering work;
- Talent expectations; and
- Talent recruitment processes.

Based on the the data, the research team outlined some recommendations for employers, future workers and educators in the areas of:

- Growth of “green” engineering that will impact all engineering disciplines and employers;
- Deepening communication loops among employers and educators; and
- Changes to curricula to better meet student/employer needs.

THE ENGINEERING CONTEXT

The increasing use of computers for all aspects of engineering is changing the way people work together. Employers increasingly expect their engineers to have both technical depth and an holistic perspective about how their engineering work fits with other engineering functions. They also expect their engineer employees to understand how their work impacts other business functions such as marketing and overall profit and loss. As a result, interpersonal skills, project management, and problem solving skills continue to be vital areas of expertise that engineers must bring to their jobs.

Hiring Demand

Even in this economic climate, demand for engineering talent from all kinds of disciplines remains strong overall,

though companies did report through the employer survey that their applicant pool is far larger than the number of open positions presently. To uncover differences in demand for engineers with four-year degrees and engineering technicians who have two-year degrees, we asked companies to predict demand for both types of jobs. A substantial number of companies indicated that they have more open jobs than applicants in the following areas:

- Computer software engineers
- Electrical engineers
- Mechanical engineers

Areas in which the applicant volume roughly meets the volume of open positions are:

- Chemical Engineers
- Material Engineers
- CAD/Design Technician

In the future, employers anticipate their talent demand to increase, so that supply will roughly equal demand. The areas with the most expected demand in the future are:

- Computer software engineers
- Electrical engineers
- Mechanical engineers
- CAD/Design Technician

Broad Engineering Challenges Center on Workforce

While keeping pace with technological change, meeting evolving customer expectations and increasing productivity emerged as broad engineering challenges employers face, workforce issues (recruiting, hiring and retaining talent) resonated as a critical engineering challenge, not just an HR issue. We should emphasize that the focus on workforce was constant, irrespective of company size. This workforce focus included the talent pipeline and the

continued emphasis of soft skills such as interpersonal communication and project management.

As one employer put it:

“[Our] biggest challenge will be training (and finding) the next generation of engineers to take over work of baby boomer engineers.”

Another said:

“Working globally across cultures, geographies and time zones, there is a need to have common computational tools and language.”

A third summed it up this way:

“Problem solving skills, analytical skills, exploiting current technology. When these are lacking, our [products] fail quality control, which is a huge cost to our bottom line.”

Core Jobs in Engineering are Changing

Throughout our research, employers consistently voiced their increasing expectation and desire for engineers who think holistically, irrespective of his or her engineering disciplinary training. This shift to a “holistic”⁴ engineer represents a fundamental shift in employer expectations. In practical terms, this attribute is manifested by engineers who have cross-discipline knowledge. We are not implying the wholesale disregard for engineering disciplines as core areas of depth of knowledge. Rather, employers emphasize the need for engineers who have a depth of knowledge in a discipline but who are familiar with other engineering disciplines, the business context, and/or other engineering functions. One large manufacturing company calls this type of engineer an “integrated engineer.” This company defines the skills and attributes of an integrated engineer in this way:

- Integrative systems thinking
- Teamwork (teaming and team dynamics)
- Project management
- Organizational change management
- Business knowledge
- Relationship development/building/management; knows how to make relationship connections and understands the importance of these connections

These engineers differ from “traditional” engineers in the breadth and variety of skills sets other than pure engineering content. This large manufacturing company is not alone in its desire for well-rounded talent. Other companies large and small expressed desire for employers who could cross functional boundaries, communicate key engineering concepts to non-engineers, and who could lead teams.

Our research findings echo those expressed in the well known volume, *The Engineer of 2020: Visions of Engineering in the New Century*, published in 2004⁵, by the National Academy of Engineering (NAE). This alignment indicates that our sample is reliable and that the results of our research on computing in engineering should be applicable to the national workforce. Our research provides an in-depth, on-the-ground perspective of how Michigan companies are experiencing global change. More specifically, our CPACE approach provides a solid approach for educational institutions to partner with industry to drive curricular change.

Computational Nature of Work Changing

An additional fundamental change over the last decade or so is the explosion of software which is changing both the computational and business nature of engineering work. Employers and employees overwhelmingly indicate that this profusion of software has increased productivity, thereby reducing lead times, costs, and increasing the ability of far-flung teams to work together. Figure 4 shows that many employees consider software to be a major productivity enhancer. In particular, productivity improved due to improved modeling capabilities, which was in turn linked to the ability to try different designs to see how they would work. Improved productivity had less to do with improved access to data. In addition, employees mentioned that software has allowed them to improve modeling and communication. When asked about expected future software use, employees said they expected continued emphasis on modeling, visualization, computer programming and document exchange.

This growth in software use is mirrored by an overall increase in computer use. We asked employees to define the ways in which they used computers to analyze, design, model or make decisions related to their jobs. We classified their responses into various categories, shown in Figure 5:

⁴ *Future of Engineering in the United States National Forum*, hosted by Heldrich Center, Harvard University’s Labor and Worklife Program and National Bureau of Economic Research, November 17, 2008.

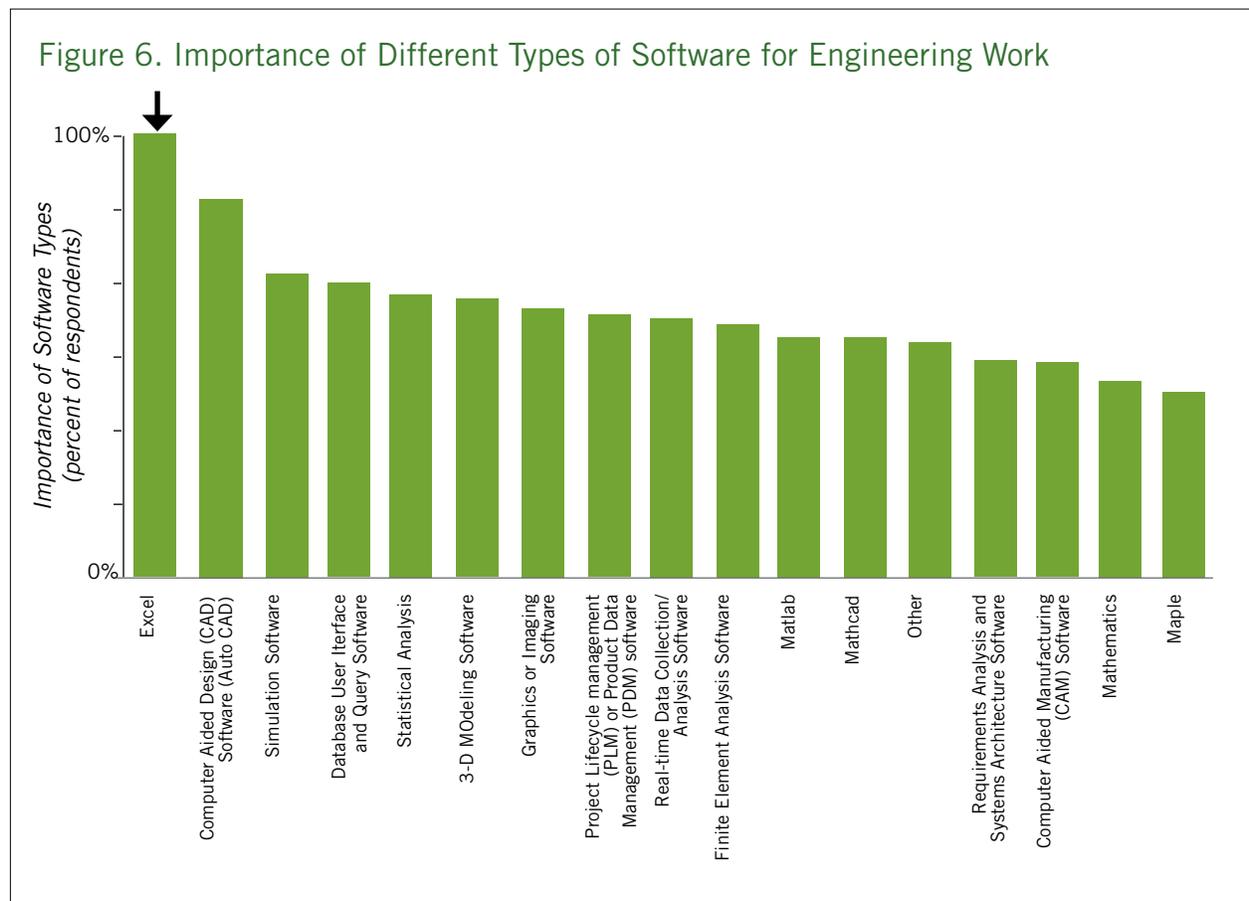
⁵ *The Engineer of 2020: Visions of Engineering in the New Century*, published in 2004, by the National Academy of Engineering (NAE) Executive Summary, http://books.nap.edu/openbook.php?record_id=11338&page=1

Figure 5 reflects several key points related to the use of software:

- Engineers use computer software extensively to do their jobs, particularly specific technical software such as GeoPak, Microstation and others. In short, absent software, engineers could not do their jobs.
- Effective use of analysis software depends on core math skills. One engineer explained it this way: “Thorough knowledge of primary mathematics, related engineering disciplines like trigonometry, calculus, algebra, and physics is needed.”
- Likewise, the category “verify computer correctness” as used in our research captures the idea that employees must understand the core engineering principles behind the software. In effect, they must understand that the computer will not “tell them the answer.” As one engineer states: “*One must understand the fundamentals of electrical engineering in order to understand how the software operates and outputs data.*”

- The high level of importance given to general computer skills reflects the large cohort of our sample ages 35-55, many of whom started in the engineering profession with far less software use. Employees commonly referred to learning to use the computer to do tasks they previously did by hand, which reinforces the related finding that computers have radically increased productivity. In addition, employees mentioned familiarity with common software tools such as the Microsoft suite of software.
- The use of spreadsheets reflects the increased use of Microsoft Excel, which is also reflected in the portion of time spent doing computer programming. Survey responses in this category reveal that many respondents use their knowledge of Visual Basic programming language, which allows users to do advanced calculations in Excel, as opposed to writing new software.

While employees clearly continue to use very specific engineering programs such as CAD, the data reveals that Excel is a crucial tool for engineers (see Figure 6).



TALENT EXPECTATIONS

Our review of the data revealed several common elements, both computational and non-computational, that employers expect of their new talent. Since these expectations all build on the idea of a holistic or “integrated” engineer, it is not easy to draw out computational skills that are isolated from other skills. For the purposes of this report, we define translating between the conceptual and operational, managing data, using software and increasing business productivity as primarily computational skills. We consider soft skills to be adaptive thinking and understanding the business as primarily non-computational skills. Employers seek all of these skills irrespective of company size or industry representation. Further, companies expect these skills sets to become more important over time, raising implications for future engineers and engineering programs. We outline several key skill-related trends below.

Interpersonal skills and/or general management skills emerged as one of the most common skill sets employees mentioned as an attribute they need to be successful in their job and one which they felt was not part of their formal educational experience.

Non-Computational Skill Sets

These skills sets reflect attributes needed for career success, and are generally less computational in nature. We categorized the non-computational skill sets in three categories.

1. **Soft skills highly valued.** While key engineering skills and practices remain essential, employers and employees alike articulated the critical business imperative of interpersonal skills, communication and teamwork, what we term loosely here as “soft skills.” In fact, interpersonal skills and/or general management skills emerged as one of the most common skill sets employees mentioned as an attribute they need to be successful in their job and one which they felt was not part of their formal educational experience. While such skills have always been important, they have gained prominence with the increase in team project work, increasing virtual and international team membership, and increasingly reduced

lead times for projects. Engineers are also being asked to communicate the value of their company’s projects to non-technical audiences such as community stakeholders, environmental advocates, and investors. Likewise, increasing globalization means that engineers are working with peers and supervisors of various backgrounds and cultures. Implicit in successful teamwork are the skills associated with valuing and leveraging diversity.

Commonly mentioned soft (i.e. professional) skills include:

- Interpersonal communications
- Effective written communication
- Managing teams
- Resolving conflict
- Working effectively with diverse teams
- Project management
- Systems thinking
- Process management

It must be emphasized here that lack of effective teamwork skills or a lack of soft skills is often a deal breaker for companies in offering a position to a candidate. While technical skills and knowledge are important, they are an expected “given” for employers, and it is in the realm of interpersonal skills where hiring decisions often get made. The employee survey responses reinforce that employees felt that their educational experience did not give them enough opportunity to grow these skills they needed for job success.

In addition to expectations that any engineer in any core job would require effective soft skills, an additional skill set often mentioned by employers and employees alike was project management. Project management

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includes understanding overall project objectives, which could include deliverables from other departments. Project management reinforces the desire for engineering staff to understand the business context of the project or product they are trying to develop. Many employees mentioned project management as a skill set they need in their current job which was not part of their engineering curriculum.

Employers echoed this desire for project management skills, not just familiarity with a specific project management software program.

2. Increasing use of adaptive thinking. Similarly, employers expect their engineers to engage in what we call “adaptive thinking.” This perspective involves critical thinking, innovative thinking, and problem solving to conceptualize solutions or to determine root causes. Employers compared this attribute to an unwanted overreliance by engineers on software to produce answers. An employee who lacked adaptive thinking would input various criteria into a software system and rely on the software’s proposed model or solution as the correct answer. That employee might fail to notice that a critical assumption or constraint was missing, or that the model was suggesting an answer that was nonsensical or inaccurate. Likewise, in using software or control systems that self-diagnose problems, an engineer would take at face value the software’s diagnosis. In contrast, an adaptive thinker would question the software’s assumptions, think about the key problem, or integrate seemingly unrelated data into his or her thinking. An engineer using adaptive thinking must understand the core principles at work. In fact, employees often referred to what we call “verifying computer output correctness.” This behavior entails double-checking simulation outputs, for example, or using Excel to give a rough estimate of an expected outcome and comparing that to a specific software output.

This perspective involves critical thinking, innovative thinking, and problem solving to conceptualize solutions or to determine root causes.

As one civil engineering employee put it:
“The engineer must be able to review computer output for reasonableness and ensure correctness of the drawings and calculations. The computer is a tool that will do what the engineer instructs. The engineer needs to understand material strength, geometric properties, be able to perform interpretive analysis for engineering problems.”

A design engineer wrote:

“Sufficient background in electromagnetics/physics/engineering [is required] to know when computational code outputs are nonsense or incorrect.”

An employer stated:

“It is essential that individuals understand that when they are using computational tools, they must know what they are calculating, what the calculation is saying, and be able to judge if a calculation is correct. (The ability to do manual calculations is also still important to enable one to check or question their work and analysis)... Computational tools allows engineers/technicians to make rapid changes, increase productivity, and evaluate various scenarios/options. This sometimes causes paralysis as new engineers have a tendency to over-analyze things and are not able to make critical choices.”

A key element of adaptive thinking is considering processes and systems broadly. This kind of thinking includes conceptualizing how various software control systems on machines, for example, provide data that when analyzed as a whole provide a picture of how the entire process is working. Another example is understanding how water drainage systems, erosion patterns and stress load patterns impact the overall stability of a bridge. A person utilizing systems thinking would consider the impact and consequences of changing one element of a design or process on the entire system. This kind of thinking applies to the business context, not just the technical aspects of the job. For example, a new product line could be developed out of change in process, or a change in process, while increasing efficiency, would drive up costs in such a way that the efficiency gains are outweighed by cost considerations.

Another key element of adaptive thinking is taking a cross disciplinary approach to problem solving and innovation. While employers understand and value the depth a certain discipline provides, they also value engineers who can think across disciplines, who learn from and pick up ideas from other disciplines. Employers talk about blended disciplines or blended knowledge. Some of this blending happens naturally in an employee’s career, as she/he starts out in a very defined mechanical engineering position but over the course of a career ends up managing projects with electrical or chemical components, or takes a position in another company where most of the product line is chemical even though she/he has a mechanical

background. Increasingly, employers are seeking this kind of mixed discipline experience in their new hires. The benefit to employers is that new staff sees and make connections among data and peers faster and raise productivity as a result.

Successful engineers, no matter their position in the company, enhance their productivity when they understand key business principles. Both employers and employees value this attribute highly.

3. Understanding the business context. Successful engineers, no matter their position in the company, enhance their productivity when they understand key business principles. Both employers and employees value this attribute highly. Unlike a problem in an academic setting, which may focus mostly on illuminating engineering principles, engineering projects within companies are bounded by budgetary constraints, staffing levels, a division or department's stature within the company, and other business realities. Employers referenced the need for staff to design within budget, to design to customer requirements, and to generally understand the overall business goals for the company. This understanding also relates to valuing and working with people of various cultures and backgrounds; in the business context, diversity is imperative. Employee survey responses revealed that employees recognized the value of business or management skills, but they had not received this training or exposure to the degree needed in their educational experience.

In one large firm with extensive student recruitment, new hires were placed into a rotational program. In many cases, attrition in the program occurred due to a new hire's inability to understand the business context of the products being developed for a specific client, rather than a lack of technical knowledge. The hiring manager believed this attrition was healthy because he needed staff who could successfully work within a business environment—understanding budget constraints and customer timelines, for example—though he would have liked his incoming staff to have more skills in that area.



Computational Thinking

We define computational thinking as using computers to analyze, design, model or make decisions as part of the engineering practice. We categorized a variety of computational skills uncovered in the research into four key categories.

1. Translate between conceptual and operational

The skills and mindset associated with adaptive thinking carries over into the ability to translate between the virtual and physical world. With the growth in modeling software, more and more design work is being done on the computer. Engineers must spend time on the actual plant floor, machine shop, or construction site to see their projects in operation. Understanding a malfunctioning steam system in the operational context of the actual plant is very different from modeling its temperature constraints on the computer during the design phase. In the survey, employees were asked how effectively their education prepared them for their first job; the most frequent reason why employees said their education did not prepare them was that it was too theoretical and not practical enough. *Successful engineers can understand and problem-solve both at the operational and conceptual level.*

2. Manage data to make meaning. One of the most noticeable changes in business and engineering over the last decade is the profusion of data. Most machines now are computerized, providing their

own data about how they are operating or why they are not working. Consider the case of an engineer studying a manufacturing process, sitting with data reports from 15 machines, each with 20 different metrics. What is the bottom line? Which data are most important? This drive to determine meaning has led to the widespread industry use of “dash-board indicators.” These indicators are the questions where adaptive thinking becomes so critical. An engineer now has to make meaning out of the data to articulate how a process is truly functioning, or to diagnose on her own what is happening when the data can’t provide an answer. This concept was

It is vital that engineers are able to collect, organize, analyze and make meaning of the data and information and to be able to translate, broker, and share that information with others in a meaningful way.

referenced earlier in the report as well in discussing how engineers spend time “verifying computer correctness.” This need to determine meaning can be characterized as the important skill of data and information knowledge management skills. It is vital that engineers are able to collect, organize, analyze and make meaning of the data and information and to be able to translate, broker, and share that information with others in a meaningful way.

- 3. Comfort with multiple software and computational systems.** Employers and students alike recognize that students will not learn nor can the post-secondary educational system teach every software and computational system currently on the market. Employers do expect however, that incoming engineers will be familiar with one, two or three systems, even if these are not the systems the employer uses. Employer survey results reveal company expectations on programming ability (such as writing in C++) by entry level staff varies from “novice” to “expert” depending on the actual job. In many cases, specific programming skills are not required. The important skill for the new engineer is to quickly pick up on

the relevant systems needed for the job. Familiarity with a particular software system, coupled with the ability to grasp a new system if needed, is crucial. Likewise, depending on the engineering discipline, understanding that various systems do not share the same operating principles can also be important.

- 4. Using technology to increase business productivity.** Employees and employers discussed the value of using software technologies such as virtual meetings, instant messaging, and collaborative tools that allow for real-time input on a global scale, to drive business productivity. No matter the engineering position, skills in business software such as email, Microsoft Excel, and project management enhance the effectiveness of engineers.

Discussing the productivity software can provide, one materials engineer wrote:

Need to be able to understand the capability of the software: what it can and can't do. Otherwise you may estimate the time it takes to complete a job inaccurately.

In many firms, Microsoft Excel is considered a fundamental computational tool, mentioned more often than engineering-specific software programs. Employees named Excel frequently as mission critical software. Employers expect a high level of Excel competency, including use of advanced functions and macros writing. This level of competency can be self-taught, but is most often gained

Microsoft Excel is considered a fundamental computational tool.

from formal classes on Excel. Employers describe instances where an employee will run a macro to test a modeling hypothesis as a first step, then use more detailed software such as Pro-Engineer to run a full simulation. Excel is actually considered a productivity enhancer because it can serve as a quick check prior to more extensive data inputting and manipulation in other software systems. Since both technical and non-technical staffs use Excel extensively around the globe, information is often shared via this tool.

As one employee put it,

[Excel] is easily used and widely understood. As a communication tool for data, pictures, text, etc. It has few peers.

Another said,

I thought of the software that I couldn't do without and it is Excel. It can calculate, program, database, and graph. I can do everything. So it is the tool that can do the most.

One absolutely fundamental expectation that came through the interview process was employers' expectation that new hires will be able to apply basic computational concepts easily in a variety of settings.

RECRUITING TALENT

Our research also examined how employers acquire entry level talent. This section of the report outlines the processes companies use to recruit talent, and importantly, how they communicate their talent expectations to educational institutions.

Prerequisites to Hiring

For entry-level hires, companies expect a four-year degree for their engineers and a two-year degree for engineering technicians. It is no surprise that companies consider several of the key attributes listed in the previous section as prerequisites to hiring:

- Familiarity with software systems
- Facility with core computational concepts
- Adaptive thinking
- Soft skills (communication skills, teamwork, relationship building)
- Project management
- Knowledge management

The familiarity with software systems varies somewhat by company. Design-heavy firms tend to expect deep knowledge in software like MATLAB. Other firms that work with fluids or chemicals may expect knowledge in specific fluid modeling software. Other companies that use in-house software acknowledge that incoming hires won't know their specific software, but expect staff to learn it quickly.

One absolutely fundamental expectation that came through the interview process was employers' expectation that new hires will be able to apply basic computational concepts easily in a variety of settings. Employers expect that staff can use their own understanding of computational concepts to discern process or design flows, rather than relying on using a computer to "tell them the answer." We described this earlier as adaptive thinking.

The Recruiting Process

While all the companies interviewed for this project hire talent from established educational institutions, company size clearly impacts the scope and intensity of the recruiting process. Large firms have extensive recruiting processes at a number of targeted universities throughout the U.S. These firms hire dozens of students during a calendar year. The school's reputation, the performance of its alumni and interns in the company, the recruiters' and management staff's relationship with professors and the career services staff at a particular university, are all factors considered



Company involvement in a school's project-based learning experience for students is another opportunity to assess talent and for students to gain practical experience.

by hiring managers in both the decision to recruit talent from that institution and in a candidate's application for hire. Large companies with extensive "on campus" student recruitment processes often are in the fortunate position of having excess demand from students for open positions. With product lines and staffing that span multiple disciplines, they can afford to specify the engineering discipline they prefer for a particular position, though this preference does not preclude an engineer from a different discipline from applying. Smaller firms tend to hire for function specific skills, given that a position might likely require knowledge in more than one discipline.

Most companies use a number of interviewing techniques to assess candidates, including conducting multiple interviews, using behaviorally-based interview questions to

uncover soft skill attributes, and assessing specific technical capabilities. Companies use behavioral questions and panel interviews to assess interpersonal and soft skills. In addition, firms often used a technical expert to question the candidate on his or her knowledge of technical engineering detail, while hiring managers or HR staff questioned the candidate on soft skills and general fit with the company. The use of specific assessments varies across companies as well; many companies in the sample indicated they did not use formal assessment tools. Often used between the first and second interview, assessments are tests candidates take to determine how well they know a particular software suite, for example, or test a set of engineering knowledge. Assessments are sometimes used by companies when they recruit from a wide variety of sources and lack a detailed conception of the software or skills taught in a particular engineering curriculum. Like SATs or other standardized tests, assessments allow companies to standardize information about their talent pool. Generally, companies develop their assessments in-house.

Internships are the primary tool companies use to ensure that potential talent has both the theory and practical experience they seek. Internships also serve the needs of the company and the potential hire by making sure the fit is good on both sides. Company involvement in a school's project-based learning experience for students is another opportunity to assess talent and for students to gain practical experience. Project-based learning is an instructional method where students work in teams to solve a "real-life" problem, which often requires synthesizing knowledge from various disciplines or conceptual models. Employers often emphasized the importance of project-based learning opportunities occurring earlier in a student's academic life cycle rather than later. Sometimes students can spend an entire semester on one project, analyzing it from the technical, feasibility, and business contexts. Project-based learning often increases a student's skills in various talent expectations such as interpersonal skills, adaptive thinking, and moving from the conceptual to the operational.

Feedback Loop to Educators

Employers give feedback to universities and community colleges about the quality of their students as potential hires in a number of ways. Foremost is the number of hires by a company from the school. More nuanced engagement takes the form of specific relationships with professors, participation on schools' curricula advisory

boards, or feedback to the career services departments. Many large companies leverage all of these avenues and become intimately familiar with the engineering curricula or collaborate with professors on curriculum development or project-based learning experiences. Smaller companies utilize these methods as well, but they often face more constraints in terms of time their staff can allocate to these activities. Established internship or co-op programs can also provide extensive visibility into a schools' curriculum, since the staff at a particular company can see the volume of knowledge an intern brings to the experience.

Building Out Skills Sets upon Hire

No matter what skills and background new employees bring to new positions, they must learn the unique settings and processes of the company to be fully successful and productive. This new knowledge ranges from the mundane, like training employees on internal company procedures, to the specialized, such as formal training on company-specific software. Virtually all employers indicated that they rely on mentoring, both informal and formal, to convey necessary information and training. Much has been written in human resources literature and the popular press on effective orientation. In the context of this research, we asked about the on-the-job training new hires received on computational software and mission critical software. A few companies have a formal training process to orient staff to company-specific software, or to increase depth of knowledge of common software programs like Microsoft Excel. This training ranged from self-paced online training to classroom instruction. One company interviewed has a specific training program for its assembly staff, most of whom have two year degrees, to attain "engineer" positions within the company. From the company's perspective, this training provides them with a talent pipeline at less cost than recruiting and provides career advancement to its employees. One or two large companies provide their own software training. However, formal training and mentoring is rare compared to informal mentoring.

SUMMARY

Employers spend considerable effort finding the right talent for their companies, and students benefit from exposure to companies through experiences like internships. Employers made it clear that soft skills are just as important as computational skills to their hiring decisions. ■

Implications

The changing nature of engineering work and the increased use of software represent a shift in needed computational skills. Employers' expectations for a more integrated or holistic engineer, the increasing importance of soft-skills, and the need for more project-based experiences in the classroom have a number of implications for change. We, the CPACE research team, outline those implications here in three broad categories and make specific recommendations to consider.

- Link to “greener” engineering jobs/sustainability
- Employer actions to improve the talent pipeline
- Educational institutions' actions to improve the talent pipeline

GROWTH OF “GREEN” ENGINEERING WILL IMPACT ALL ENGINEERING DISCIPLINES AND EMPLOYERS.

In addition to the “integrated” or holistic engineer concept, the other major engineering shift articulated by employers is the shift to “green.” The push by consumers, the public sector and business for sustainable products and processes is impacting every industry and presenting new market opportunities and revenue streams for savvy employers. Known as “sustainable design,” “design for the environment,” designing for a “lifecycle” or “cradle to grave” in the engineering realm, the concept represents designing and manufacturing more environmentally friendly products, executing that process in a more environmentally friendly way, and developing remediation techniques to retrofit previously polluting products or processes. The shift to green impacts every engineering discipline. Renewable energy industries such as wind, solar, and biofuels, and industries involved in energy efficiency, such as next generation lighting, carbon reduction techniques, and much of the construction industry employ all types of engineers.

The implications for educational institutions are extensive, ranging from developing new curricula, updating curricula, and changing behavior. The current generation of students already has a deep interest in sustainability and “going green,” so generating student demand to study these topics is not an issue. Rather, relevant green subject matter must be incorporated into current curricula. The curricula changes include potential impact on computa-

tional skills, such as new software programs or applying engineering principles to new innovations. Some colleges, such as Kalamazoo Community College, are installing renewable energy mechanisms on their campuses and designing curricula to match. In electrical engineering, for example, solar industry employers need engineers who understand the electrical interface of a solar panel to a typical residential home wiring system. This content is currently being addressed in some classroom settings, but is also being covered by industry associations who see the need to increase the content knowledge of incumbent workers.

In other examples, student groups interested in sustainability are conducting research on ways the university or college itself can reduce its energy consumption, such as removing food trays from cafeterias to cut down on water waste and electricity use, or conducting information campaigns to convince students and faculty to use revolving doors, which reduce heating and cooling demands on a building's HVAC system.

Likewise, staff and customer expectations drive employers to improve both internal manufacturing processes and energy usage patterns. LEED certification has driven design and construction industry change and expectations on what new hires should know. The motor vehicle industry's move to electrification foreshadows changing expectations for new hire knowledge. Oil and gas companies and small start-up firms are now major investors in renewable energy production and manufacturing. Appliance and furniture manufacturers are shifting product lines to meet consumer expectations and grow new business. Across the board,

these industry shifts suggest changing expectations by employers for what future hires should know.

EMPLOYER ACTIONS TO IMPROVE THE TALENT PIPELINE

We recommend that employers consider three efforts to improve their talent pipeline; the first two relate to relationships with educators and the last deals with internal processes.

1. **Computational skills.** Deepen and improve the feedback loop with curricula committees and faculty on computational skills and “adaptive thinking.” Employers can draw considerable value from relationships with university faculty and career staff. We suggest that employers focus more on these relationships to collaborate on project-based learning experiences for students. Such experiences would provide faculty with real world problems, students with “work like” projects, and help build the university’s knowledge of the “state of the art” trends and issues in engineering fields.
2. **Non-computational skills.** Strengthen the feedback loop with educators about soft skills, both in career services and in the curricula. The overwhelming feedback from employers about the value of soft skills, project management skills and use of information technology reinforces the idea that the whole package of skills a student brings to a potential employer is of paramount importance. Career services often run programs in soft-skills, or at minimum communicate to students what employers expect about employee skills. Classroom experiences such as team-based projects can also provide students with opportunities to develop interpersonal skills.
3. **Employee orientation investment.** Employee turnover is highest in the first year of employment. While mentoring is a critical first step many companies mentioned, the more formalized employee orientation process known as onboarding can dramatically improve productivity. Onboarding goes beyond the standard human resource orientation to company policies and paperwork. It helps to reaffirm a new hire’s decision to join the company and integrates him or her into the company culture, thereby promoting retention. Onboarding should span the

first six months of a new hire’s time with a company. Effective companies use the onboarding process to help the new employee establish internal networks across departments, which can shorten time it takes for new hires to become productive.⁶

UNIVERSITIES/COMMUNITY COLLEGES ACTIONS TO IMPROVE THE TALENT PIPELINE

Educational institutions can use a variety of options to more closely align the skills undergraduates learn with those that employers seek.

1. **Computational skills.** Project-based learning experiences should be embedded in the curriculum throughout all four years of the program. While many schools offer a senior level project, we strongly encourage incorporating this type of experience starting at entry level classes and continuing throughout the curricula. Faculty and other stakeholders can determine which series of classes are best suited to include project-based learning and create a continuum of experiences for students. It should be reinforced here that co-op and summer internships are not what we mean by project-based learning experiences; the former are “on the job” experiences shaped wholly by the employer, whereas project based learning experiences are shaped by both faculty and industry. Some engineering educators are taking the approach of using the computer science department to help design real world problems suggested by industry for engineering students that emphasize engineering principles and computational skills.



⁶ *Small Business Resource Guide: Recruiting and Retaining Employees in a Shifting Economy*, <http://findtalent-keepalent.wikispaces.com/Retention>

Given employers' emphasis on the ability to move from the conceptual to the operational, educational institutions should also consider ways in which students can gain experiences that are as close to those of working engineers as possible. Site visits to employers' production locations are one example of seeing machines "in action." Student design and build competitions are another avenue for this type of experience.

2. **Non-computational skills.** Expanding cross-departmental collaboration is another way to develop holistic or integrated engineers. Employers' emphasis on cross-discipline or integrated engineers reinforces the idea that engineers should have experience with various types of engineering, so that in they can leverage others' expertise, add to their own, or make cross-functional connections. Cross-listed classes, team-taught classes, or extensive guest lectures from

other departments are examples that give students multiple perspectives within one class. Speaker series that address a topics from other disciplines provide another opportunity for students to understand a problem from multiple perspectives.

3. **Employer engagement.** Proactively engaging and learning from employers as part of a comprehensive feedback loop can improve the fit between student's knowledge and experience and employer's talent expectations. Again, this feedback loop should also include faculty as well as career services. While curriculum committees with private sector representation are important, they are not sufficient. Likewise, while a robust internship program is the foundation for helping students gain real world experience and career exposure, the other ideas discussed here represent prime examples of a comprehensive and year round employer relationship. ■

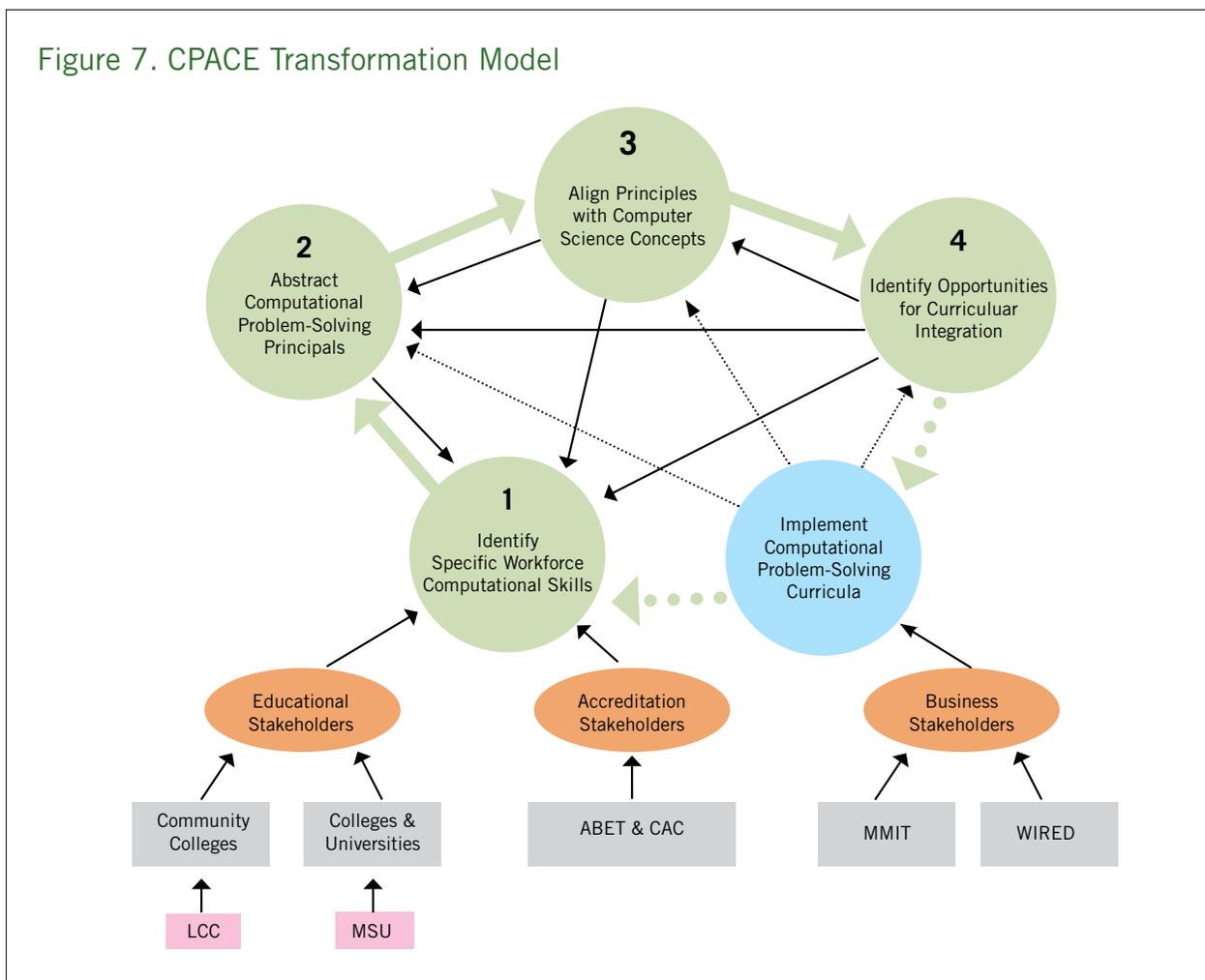
Future Directions

We have outlined the ways in which employers, students, and educational institutions can act upon the findings of this stage of the CPACE project in the short and medium term. The longer term change from this project involves curricula change, which is discussed below.

The CPACE process is based on a Transformation Model, the graphic for which is repeated here as Figure 7. The process has five phases:

1. Interview and survey stakeholders to identify specific workforce computational skills.
2. Abstract computational problem-solving principles from those skills.
3. Align those principles with computer science concepts
4. Identify opportunities for curricular integration between computer science concepts and engineering curricula. Key concepts can be interwoven among concepts to map the problem-solving requirements onto underlying computer science concepts that are the foundation of the computer science discipline. Check this alignment with stakeholders to confirm that they capture important skills.
5. Implement computational problem-solving curricula.

Figure 7. CPACE Transformation Model



the disciplines to result in a strong set of problem-solving skills that address workforce needs.

5. Implement computational problem-solving revisions in engineering curricula.

Since the particular workforce-related computational skills are unique to particular disciplines, industries or even companies, it is important to find common principles that can be used to guide curriculum design. In the next step of the process, we align these skills with computational problem solving principles from computer science to identify common features among industry and discipline-specific skills.

In the third step of the process, we are using Wing’s Computational Thinking framework to organize the computing concepts. According to Wing, “computational thinking” is a fundamental skill for everyone (especially engineers) and involves solving problems and designing systems by drawing on fundamental computer science concepts. Computational thinking includes:

- formulating difficult problems into ones that can be solved by reduction, transformation or simulation
- thinking recursively

Since the particular workforce-related computational skills are unique to particular disciplines, industries or even companies, it is important to find common principles that can be used to guide curriculum design.

- using abstraction and decomposition to address challenging design problems
- using heuristic reasoning in the face of uncertainty.

These are all crucial skills for the engineering workforce.

The fourth step in the process is to use these concepts to find opportunities for curricular integration. Computation for engineering cannot simply be addressed with one or two courses in computing, but must be integrated as part of an engineer’s training to become a “habit of mind.” We will introduce a series of authentic engineering problems derived from industry that require the use of various computing concepts for their solution. These problems will be part of engineering courses, but will be developed in consultation with employers, employees, and

Table 3. Chemical Engineering Course Concepts

	Concept 1	Concept 2	Concept 3	Concept 4	...	Concept N
Year 1	-	-	Intro to Engineering Modeling	Intro to Engineering Modeling	Intro to Engineering Modeling	Intro to Engineering Modeling
Year 2	Material & Energy Balances	Modeling Analysis & Transport Phenomena	--	--	Modeling Analysis & Transport Phenomena	Material & Energy Balances
Year 3	Mass Transfer & Separations	-	Mass Transfer & Separations	-	Mass Transfer & Separations	-
Year 4	Process Control	Process Design & Optimization I	Process Design & Optimization I	Process Design & Optimization II	Process Design & Optimization I	Process Design & Optimization II

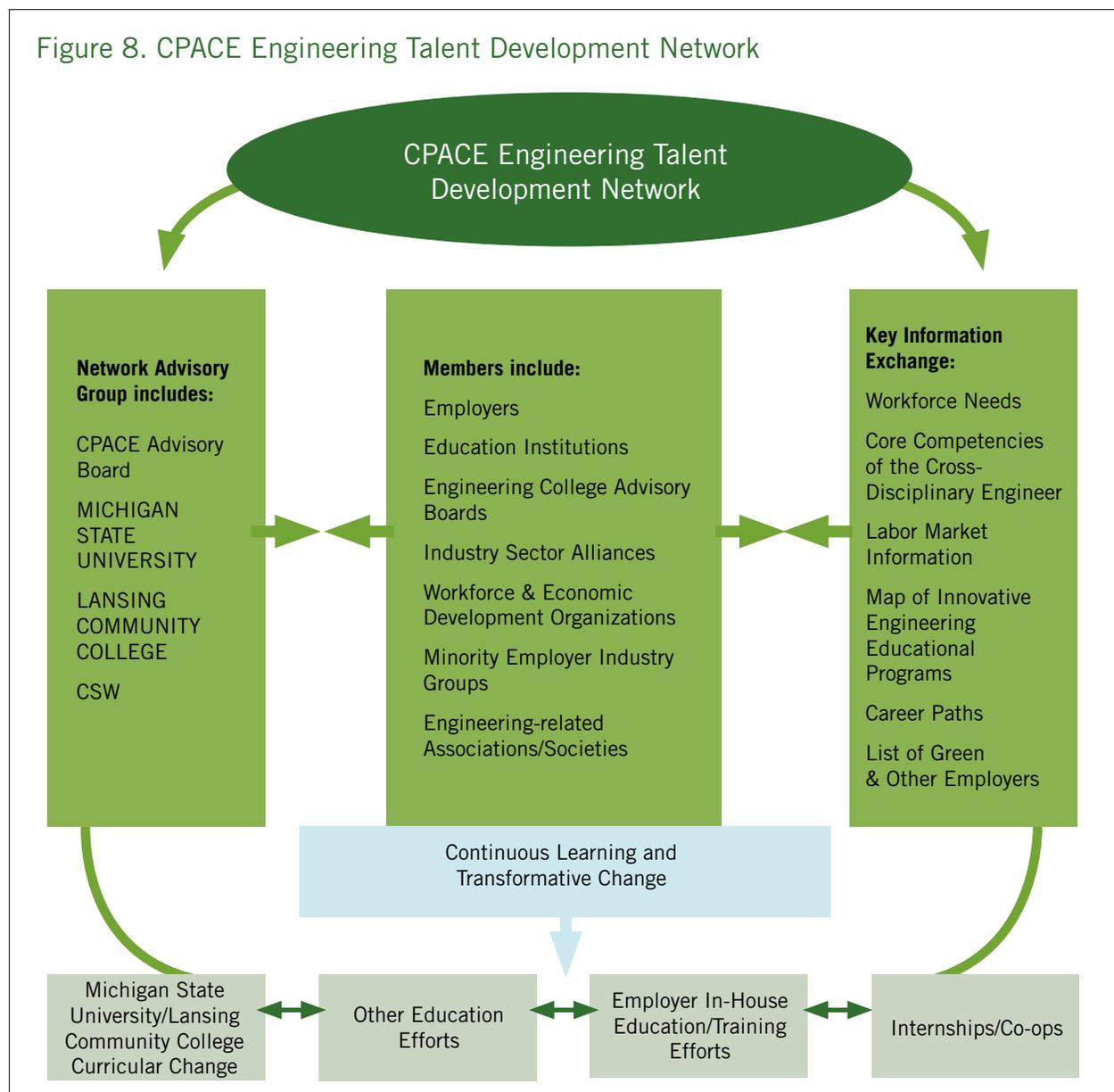
faculty stakeholders from engineering disciplines and computer science to ensure that the problems represent the use of true engineering practice and computing concepts.

In order to accomplish this, we will map the concepts across all four years of the engineering curriculum. With help from key stakeholders, we will identify problems from employers that are appropriate to a variety of courses and could be used with varying degrees of complexity. For instance, first year courses would use more simplified versions of problems. As students progress through their programs, the problems would become more complex.

However, the underlying computing concepts would be addressed across the various courses and throughout the degree program. For example, in Chemical Engineering, concepts might be distributed across courses as shown in Table 3.

We have submitted a proposal to the National Science Foundation to implement this integrated curriculum at Michigan State University and Lansing Community College. One of the project's many triumphs will be the collaboration that occurs among employer, education, employee, and workforce development stakeholders to

Figure 8. CPACE Engineering Talent Development Network



identify business problems that can be used in different disciplines in order to help develop engineers with a holistic skill set.

The evolution of this collaboration will take the shape of a CPACE Talent Development Network (Figure 8.). Members would be initially identified through the network advisory group which includes the CPACE Advisory Group, Michigan State University, Lansing Community College, and CSW. Once convened, the members of the network will meet periodically to:

- Exchange ideas on how to collaboratively provide authentic engineering-based learning experiences through internship opportunities and by sharing real engineering problems that require the use of various computing concepts for their solution.
- Contribute to and encourage knowledge transfer and information exchange such as workforce competency needs, labor market information, and

computational-based academic research between employers and educators.

- Inform and support talent strategies that will further promote educators, employers and workforce/economic development professionals in thinking and acting differently relative to engineering talent development.

Ultimately, the network can serve as a mechanism to bolster, expand, and sustain ongoing employer engagement, strengthen relationships within Michigan State University and Lansing Community College engineering programs, and among other educational institutions. The network can expand work-based learning opportunities for students at all levels, integrate computational engineering skill priorities into curricula, and facilitate meaningful connections between employers, educators, and workforce/economic development professionals. ■

Conclusion

Noting the strong demand for the preparation of a globally competitive U.S. workforce with knowledge and understanding of critical computing concepts, the CPACE initiative emphasizes engaging stakeholders from multiple sectors to identify engineering computational problem-solving skills, to define how these skills can be integrated across curricula, and to revise the curricula to integrate computational problem-solving directly informed by industry needs. This process can serve as a model for national efforts to revitalize undergraduate computing education in engineering.

Our findings reveal that employers:

- a. Value soft skills such as communication, project management, and the ability to function in a team;
- b. Consider adaptive thinking a key attribute;
- c. See trends towards computational globalization which translates to the need for engineers to understand business practices and the importance of integrating engineering data across larger systems; and
- d. Value the ability of engineers to understand both engineering and computational principles that allow them to use computational tools to solve engineering problems.

In many ways, the challenges facing the engineering profession are echoed in questions related to our overall economic prosperity. How will our workforce address the critical challenges facing all of us, like decreasing the use of carbon, providing products and services in a sustainable way, and innovating new techniques? These questions reveal the fundamental role engineering plays in our economic development. We hope that the results of our research demonstrate a way for educators and industry to come together to envision the future of the engineering workforce.

If you would like more information on CPACE or how you can get involved in sharing current and future information and help sustain this transformative effort, please contact:

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