AC 2009-1809: LEVERAGING WORKFORCE NEEDS TO INFORM CURRICULAR CHANGE IN COMPUTING EDUCATION FOR ENGINEERING: THE CPACE PROJECT

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Leveraging Workforce Needs to Inform Curricular Change in Computing Education for Engineering: The CPACE Project

Abstract

Traditionally, industry computational needs have been couched in terms of proficiency with specific applications rather than around functional computational capabilities. In this global economy, the preparation of a globally competitive U.S. workforce with knowledge and understanding of critical computing concepts, methodologies, and techniques is essential. A Collaborative Process to Align Computing Education with Engineering Workforce Needs (CPACE) is an NSF-funded community-building initiative that brings together Michigan State University (MSU) in partnership with Lansing Community College (LCC) and the Corporation for Skilled Workforce (CSW) to design and implement a process to transform undergraduate computing education within the engineering and technology fields. We envision that this process will serve as a model for national efforts to revitalize undergraduate computing education in engineering.

In this paper we detail the process we developed to engage a wide variety of stakeholders – business, community leaders and post-secondary educators – to collaborate on research to identify computational skills needed by the engineering workforce. We also discuss the results from our employer interviews and employee surveys. The aim of these analyses is to determine the stakeholder's assessments of the computational skills needs in their business sectors.

This research provides the foundation for revising the curricula across engineering departments to incorporate computational problem-solving tools within the various disciplinary contexts. The goal is for engineering graduates to enter the workforce with improved and practice-ready computational thinking that will enable them to problem-solve and understand computational problem-solving in the context of the principles of computer science.

A **C**ollaborative **P**rocess to **A**lign **C**omputing **E**ducation with Engineering Workforce Needs:
The CPACE initiative

There is a call for action to revise undergraduate engineering education to meet the challenges of the new era; these challenges include globalization, international competition, an increasingly diverse population, and a rapid growth in information technologies. For engineering education to prepare graduates to flourish in the new global economy, innovation and flexibility in curriculum design based on constituency input and quality improvement principles are necessary[1].
The CPACE project is designed to address these challenges in the context of computing education within engineering disciplines. CPACE brings together post secondary educators – represented by MSU and LCC – and business, industry and community leaders – represented by CSW – in a community building process to transform undergraduate computing education within the engineering and technology fields. The goal of the CPACE project is to develop a partnership among a wide variety of stakeholders to identify the computational skills that are essential for an engineering workforce for the 21st Century. The objective is to revise the engineering curricula to address computational problem-solving that is aligned with industry needs. This approach somewhat mirrors the process by which ABET accomplished a reformed evaluation criteria

based on customer focus, continuous program improvement, and outcomes in student learning[1]. We are developing a dynamic process that documents every step of the research from engaging the different stakeholders to implementing the process for curricular reform.

Project Implementation

CPACE is based on the 'Transformation Model' depicted in Figure 1. This model envisions a cyclic process with feedback among the five major nodes.

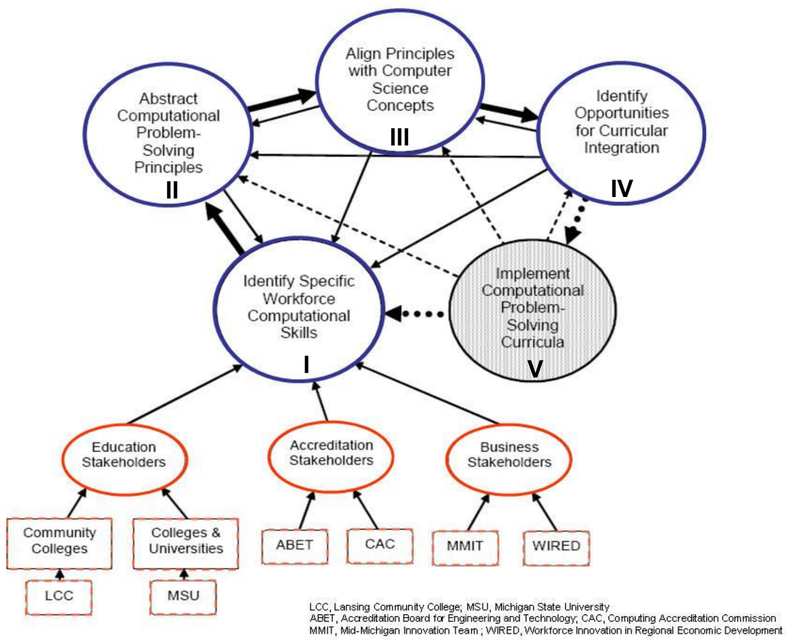

Figure 1. CPACE Transformation Model. The model provides a framework that allows all stakeholders to view their needs in the context of the entire process. The primary focus of this project is on the nodes that are highlighted in blue. The various stakeholders groups and subgroups involved in node I are highlighted in red. The shaded node indicates the curricular implementation process that will be addressed in a subsequent project.

The process comprises five stages:

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 to map the problem-solving requirements onto underlying computer science concepts that are the foundation of the computer science discipline. This alignment is checked among stakeholders to confirm that they capture important skills.
4. Identify opportunities for curricular integration that fit between the computer science concepts and engineering curricula in other departments. The abstract concepts are aligned with disciplinary problem-solving that addresses workforce needs.

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

We have divided the outcomes of the project in three phases that can be aligned with the nodes in the transformation model (Figure 1): Phase I includes the activities needed to *identify specific workforce computational skills* (node I):

- Design a work plan to identify and engage higher education and community stakeholders to explore common interests, share lessons learned and identify common practices around the issues of computing education to better prepare students for employment within engineering and technology fields.
- Engage engineering education, accreditation and business stakeholders to conduct interviews and to survey their engineering and technical employees.
- Develop interview and survey instruments to determine stakeholder's assessments of the computational skills needs in their business sectors.

Phase II includes activities related to nodes II, III and IV (Figure 1) and starts with the analysis of the employer interviews and the employees surveys to:

- Identify key computational problem solving skills in these business sectors.
- Abstract the computing principles[2] and concepts and align those principles with computer science concepts[3] that are the foundation of the computer science discipline.
- Identify opportunities for curricular integration.
- Synthesize and summarize our research from engaging the different stakeholders to the identification of opportunities for curricular integration into a concise process.

In Phase III of the project we will disseminate our findings and maintain the engagement and dialogue among the stakeholders:

- Design and hold forums and other events to communicate findings from the process and begin planning for extensive engagement.
- Engage a wider set of stakeholders in the preparation and submission of a full implementation NSF-funded grant.

At all phases of the project an external evaluator evaluates the project model and process and prepare reports of each phase of the activity. For a summary of the evaluation to this date refer to the external evaluation section below.

In the following sections we discuss the strategies that we are using to develop a process for engaging higher education and community stakeholders who have an interest in transforming undergraduate computing education. We present a detailed analysis of the employer interviews and preliminary analyses of the employee surveys developed for identifying computational skills needs in their business sectors.

Phase I. Design a work plan to identify and engage higher education and community stakeholders: Convening an advisory board

One of our first activities was to convene an advisory board (AB) charged with collaborating with the research team to refine and implement a work plan for stakeholder engagement. Our goal was to create an AB with knowledge of current engineering computing practices and likely future needs within academic and professional settings. We decided to focus on the mid-Michigan area for several reasons:

1. To build on existing regional relationships with CSW, MSU and LCC.
2. Data from MSU and LCC indicated that a large percentage of graduates from the school of engineering are employed in the region.
3. Budget constraints did not allow for extensive travel.

Another important step was to carefully select the industry representation we wanted in our AB. To inform our selection process we reviewed federally generated labor market occupation data on employment sectors and job distribution by disciplines to assure that our sample was representative of the national employment and anticipated needs in the year 2012[4]. Using this data, we generated an extensive list of representative candidates based on their discipline and industry sector.

We recruited participants from business, industry and academia who were able to provide perspectives on their sectors' needs for computational applications in the engineering practice. We looked for business, industry, professional associations, and professional society representatives who could connect us to their employers and working engineers and engineering technicians who would be able and willing to participate in interviews and surveys.
Our criteria for AB membership were:

- Understand and appreciate the important role computational skills play in 21st century engineering practice.
- Have a professional interest/stake in the project, and plan to be engaged with CPACE through August, 2009.
- Have technical engineering expertise including understanding the roles that computation plays in the field.
- Have a broad perspective on engineering computational needs and business practices.
- Help us network with a range of stakeholders within and/or across their sectors.

Our resulting AB has 14 representatives from a cross-section of engineering disciplines and industry sectors, including academia (university and community colleges), engineering societies, and business/employers. During phase I of the implementation plan, the AB collaborated with the research team on three primary tasks:

- Identify persons to engage in the larger community building activities.
- Devise processes to promote dialogue among this group of larger stakeholders.
- Develop protocols for interviewing stakeholders at engineering and technology companies in the region and developing the surveys for both employers and engineering/technical employees.

Phase I. Engage engineering education, accreditation and business stakeholders to conduct interviews and to survey their engineering and technical employees

Employer engagement

With collaboration from the AB we identified business stakeholders to interview as well as employers who allowed us to survey their employees regarding their computing education and preparation for the workplace. Our employer engagement strategy had two major components:

1) Leveraging AB responsibilities to:
   - Best benefit from their positions of influence.
   - Connect to employers and associations.
   - Offer support letters.
   - Review and provide feedback on survey and interview protocols and the engagement strategy.
2) Engaging business directly through:
   - AB affiliated and suggested businesses.
   - MSU and LCC employers who recruit their students.
   - Regional businesses contacts provided by the CSW.

To best connect with employers we gave them a concise value proposition that identified their short and long term benefits for participating in the project. To generate these value propositions we sought advice from our AB; as stakeholders they were in the best position to give their opinions. They suggested that employers could benefit through:

- Reduced and better-directed training for employees when they enter the workforce.
- Improved understanding of their engineering workforce and practices compared with other companies. Because we protect the identities of the participating companies, the companies are not at risk of revealing information that may put them at a competitive disadvantage. However, since they know their own data, they can compare it with our overall results.
- Extending and/or establishing networks.
- Having a stake in the regional new economy.

Personal contact was the best way to engage stakeholders. It often took a couple of phone calls and or e-mails to obtain participation, but in general we found that employers were very receptive and interested in collaborating with us.

Sample characteristics

We used data from the federally generated labor market occupation listing to ensure that our sample was representative of the regional and national labor market. For example, according to the North American Industry Classification System (NAICS)[4] data, 24% of engineers end up in architectural and engineering services in the upper Midwest region, so the final recommended list included 3 companies in this group. Also, NAICS[4] data indicates that 11% of engineers in this region work in motor vehicle manufacturing or motor vehicle parts manufacturing, the final recommended list included these types of companies (Table 1).

The final list of potential candidates was reduced from 50 to about 35. Important criteria that were used to choose the sample include:

- Industry sector representation
    - For industry sectors represented by more than one company we tried to include a national large company with a Michigan presence and a small company headquartered in Michigan.
    - When the company is the only example of a particular industry, they were included.
- Engineering discipline representation, including:
    - Chemical engineering
    - Mechanical engineering
    - Civil engineering
    - Electrical engineering
- Companies that hire from MSU and /or LCC.
- Recommended by AB member.
    - Likely inclusion if recommended by more than one AB member

Table 1 shows the discipline and industry sector representation of the employers that we choose to interview.

Employer	Discipline *	Industry
1	CPE, CSE	Software publishing and web development
2	CHE	Manufacturing - Plastic
3	ME, CHE, BSE	Manufacturing - bio-based products, bio-med, automotive, alternative energy, aerospace,
4	CHE, ME, CSE, ASE, EE, CPE, CIV	Engineering training/consulting services Software development
5	CHE	Manufacturing- chemical
6	CPE	IT consulting and services
7	ASE, CIV, EE, ME	Architectural and engineering consulting services
8	CHE	Manufacturing- plastics
9	ME	Motor vehicle parts manufacturing
10	CHE, EE, ME, CSE	Aerospace - motor vehicle manufacturing
11	CHE, CPE, EE, ME	Motor vehicle manufacturing
12	EE, CHE	Manufacturing- chemical, alternative energy
13	EE, ME	Manufacturing - machine tool and die
14	ME, CHE, BSE	Manufacturing - Durable Goods, Agriculture/Foods
15	CIV	Government - environmental, bio-based products, and engineering services
16	CIV	Government - transportation, architectural, environmental and engineering service
17	ME	Manufacturing - tool and die
18	ME	Manufacturing- tool and die (aerospace, alternative energy, auto, marine/naval, mechanical)

Employer	Discipline *	Industry
19	CIV, CHE	Manufacturing - steel
20	CHE, BSE, ME	Power generation and supply
21	ME, CHE, CIV	Manufacturing and Architectural and engineering services - office furniture/work environment
22	ASE, BSE	Manufacturing - aerospace, bio med
23	ME, EE, CHE	Government/Military -alternative energy, electrical, petroleum, motor vehicle parts mfg
24	CPE, CSE	Software publishing
25	ME	Manufacturing- tool and die (automotive, construction, industrial)
26	EE, ME, CHE, CSE	Manufacturing - Consumer Goods, Appliances
27	EE, ME	Electronic instrument mfg

* Civil engineer CIV, Chemical engineer CHE, Mechanical engineer ME, Electrical engineer EE, Applied Science Engineering ASE, Bio-Science Engineering BSE, Computer Program Engineering CPE, Computer Science engineer CSE

Phase I. Develop interview and survey instruments to determine stakeholder's assessments of the computational skills needs in their business sectors

Employer interview protocol and interview process

Our objective was to interview the head of engineering, human resources executives (preferably both) to understand their employees' use of computer technology and the computational skills needed in their businesses. We wanted to understand whether they see higher education institutions preparing their employees to meet the computing challenges they face and what recommendations for improvements might be made.

During the development of the instruments it was important to constantly align the instruments to the objectives. Initially, we examined existing interview protocols from the MSU College of Engineering and LCC that were designed to ask recent graduates about their perceptions of how their education prepared them for entering the workforce. The CSW also leveraged their extensive experience interviewing and surveying in industry and business settings.

The first protocol that we designed was a linear protocol in which the interviewer asked specific questions and had specific probes to obtain more detailed information where needed. When we tested this protocol, it was clear that a linear protocol was not providing us with the desired results. The flow of the interview was not smooth and the interviewees were sometimes confused about what we were asking and needed to repeat themselves. Based on the first set of pilot interviews we modified the protocol. The modifications were not so much about the content — we felt that we were asking the right questions given the objectives — but about the form of the interview. We designed a flow chart model to conduct the interview (Figure 2). The major questions were still there and we used the same probes to obtain detailed information when needed. This protocol allowed for a better flow and the interviewer would only interrupt and probe when necessary in order to get some more details about a particular subject or to find relevant information that was not yet covered. The duration of the interview is about 45 minutes.

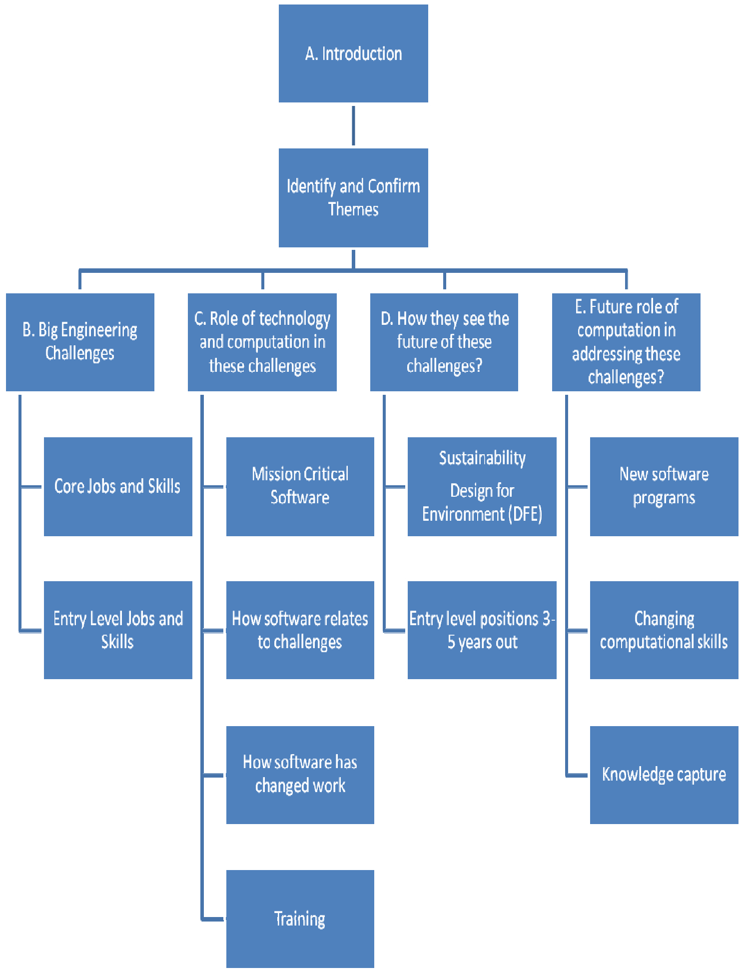

Figure 2. Employer Interview Flow Chart. The general structure for conducting the employer interviews.

Before the interview we ask the employers to complete an online demographics questionnaire. The interview begins with the introduction (Figure 2, *A: Introduction*) which includes information about the CPACE project and the goals for the project. An important part of this introduction is to review the particular goals of the interview, which are to learn more about the computational skills that the employer needs from newly graduated engineers and engineering technicians. We next define what we mean by computational skills --using computers to analyze, design, model or make decisions as part of the engineering practice.

Following the introduction, we ask the interviewee to tell us about the company's primary mission and what sets them apart from other companies. At this point the interviewer identifies two or three themes that are mission-critical and confirms with the interviewee (Figure 2; *identify and confirm themes*).

The body of the interview probes the interviewee with questions about the major engineering challenges including core engineering positions and the skill set necessary to fulfill the position (Figure 2; *box B*). We further explore in more detail the role of computation and technology in these challenges (Figure 2; *box C*) and obtain detailed information about critical software and specific uses of this software in the context of the mission critical themes identified before. Here we also get information regarding training and the relationship of the company with higher education institutions. In boxes D and E we ask the employer about their perception of the future of the engineering practice and about the role of computation in addressing these challenges (Figure 2; *boxes D and E*).

At the end of the interview we ask the interviewee for suggestions regarding companies that would be interested in participating in the interview process. We also tell them that we will share the results of our research. Appendix I shows an example of a real interview with one of the employers.

Our initial goal was to conduct 20-25 interviews; we have completed our interviewing process having conducted 27 interviews with companies representing a cross-section of engineering disciplines and different industry sectors (Table 1).

Employee survey protocol and survey process

The main objectives of the employee survey were 1) to understand what people working in engineering and technology feel are the strengths and weaknesses of their undergraduate computing education and 2) to identify current and future computational problem-solving gaps based on employee's views of future needs and trends. Our goal was to conduct electronic surveys of 250 employees of participating companies as well as leaders and members of the professional engineering societies.

During the initial stage of the survey development the majority of the questions were framed as open-ended questions; we then conducted pilot surveys to identify the primary types of responses. After these pilot surveys most of the questions were converted to close-ended items and we also kept some of the open-ended items.

The survey is web-based and begins with a brief introduction with information about the CPACE project. We explain that the objective of the survey is to reach out to engineers and engineering technicians to learn more about the skills they need on the job. We make it clear that we are focusing on computational skills. We define our meaning of computation skills--using computers to analyze, design, model or make decisions as part of the engineering practice. We also indicate that we are interested in their opinions about the future of the engineering practice hence, for a number of questions the survey will ask about future needs 3-5 years from now. The survey takes around 20 minutes to complete.

The survey has the following sections:

- Demographics
- Skills and education: Questions about degrees and basic skill set needed for their job.

- Technology: Probes about the software that the company uses to meet key engineering challenges. We ask them to identify and describe up to 3 specific software programs they consider critical to support the engineering practices of their business and to the performance of their job.
- Future software directions: We probe for specific examples about software that has changed the nature of their work and software functions that they anticipate will be critically important to support daily engineering practices over the next 3-5 years.

To date we have received more than 200 responses and we are still receiving survey responses. By the time this paper is published we should have surpassed our goal of 250 employee surveys. The surveys are helping us to:

- Determine the extent to which current employees feel college prepared them for computational problem-solving needed on the job.
- Identify educational experiences students found best prepared them for computational problem-solving.
- Identify current and future computational problem-solving gaps based on employees' views of future needs and trends.
- Explore the relationship between higher education institutions, employers and students/employees in their efforts to promote improved computational problem-solving.

Phase II. Identify key computational problem solving skills in these business sectors

Employer interviews analyses

The employer interviews were organized and analyzed using *Transana*, software that supports the transcription and analysis of large collections of video and audio data[5]. Each interview is transcribed and saved in the program; the interviews are then analyzed in detail by inserting time codes that define analytically interesting portions of the interview. This coding allowed us to move through the interview segment by segment and extract important information. We organized the results in three general categories: general skills, computational skills and future of engineering practice. These themes are summarized in Table 2. For more detail please refer to Appendix I and II which contain an example of one of the interviews (I) and specific quotes taken from the interviews that illustrate the types of responses that we assigned to each of the general categories (II).

In general the employers place a high value on a) interpersonal skills such as communication skills, the ability to organize and present data, and the ability to function in a team; b) critical and innovative thinking as well as problem solving; c) engineers who understand business practices and the importance of integrating engineering data across larger systems and computational globalization; and d) engineers who understand engineering principles and can use computational tools to solve engineering problems by moving between abstractions in software and physical systems.

Table 2: Categories of skills identified by the employers

General Skills	Computational Aspects	Future of Engineering Practice
• Communication skills • Team work • Critical thinking • Innovative thinking • Problem solving (both conceptual and operational) • Ability to learn/adapt	• Need basic computational skills. Job-specific skills can be picked up on the job • Understanding of principles, application and limitations of computational tools • Using technology to collaborate across/outside the organization • Use of technology to support broad problem solving and decision making • Familiarity with multiple software systems, which may or may not share general operating principles • Ability to move between abstractions in software and physical systems • Multiple CAD programs including 3D modeling • Process simulation packages • Numeric computational platforms • Excel (High level capabilities) • MS Office • Knowledge of some programming	• Corporate development, leadership, management skills. Project management software • Increasing integration of engineering data across larger systems • More business intelligence embedded in systems • Data Mining • Globalization, working with global timetables • Environmental impact across disciplines. Design for the environment (DFE) • Research and development including: - New applications for existing materials - Material development - Electronic communication - Next generation of technology - Increasing use of simulation to reduce materials usage in design phase

Employee survey analyses

At the time of writing, we are just beginning to analyze the surveys. Preliminary analyses of the employee surveys indicate an agreement regarding the skills required for engineering and technical engineering graduates to perform problem solving using computer tools. For example, we asked about the importance of a new engineer's knowledge of and skills in several specific tools or general categories of software. The responses are summarized in Figure 3 below:

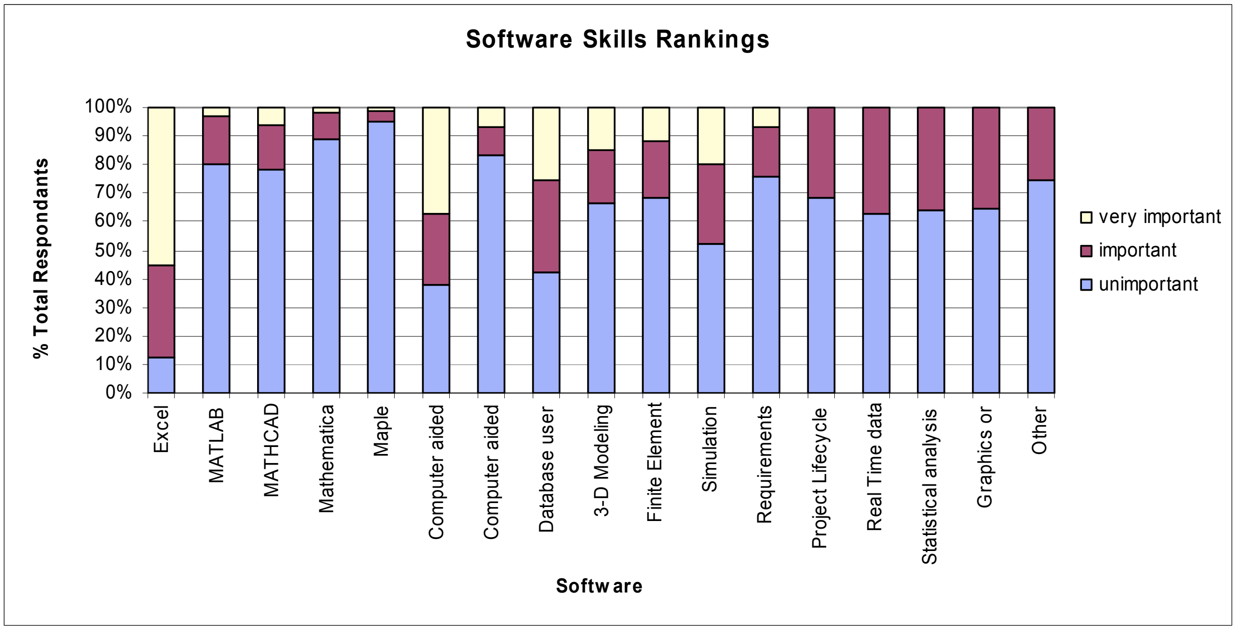

Figure 3. Software Skills Ranking. Engineers ranking of the importance of specific computational tools.

Comparing the survey responses to the employer interview data we see that engineers and engineering technicians consider tools such as Excel, CAD programs, process simulation packages, project lifecycle management software, real time data analysis software, statistical analysis software either very important or important. Symbolic mathematical software, real time data collection, data analysis and PLM software are less important.

External Evaluation

By documenting, evaluating and making this process explicit, the CPACE model should be extensible to other computing education reform efforts. To that end, the external evaluator has been collecting data on the project activity and conducted a focus group with key project stakeholders.

One of the major strengths of the project that the evaluator identified is the strong collaborative nature of the project team. Our partnership is strengthened by having both academic sectors – MSU and LCC – and the workforce sector represented by CSW. Each partner brings important skills and resources to the project. It is important to point out that establishing an effective partnership takes time because of the different perspectives brought by the partners. It took

longer than we expected to 'get to the same page;' clear project boundaries had to be established and a common language had to be identified. The magnitude of the project has been a challenge, but it has been effectively addressed through the collaborative nature of the partnership; there is a willingness to address issues and resolve them.
The Advisory Board (AB) has been one of the elements of the project that exceeded expectations. We have had two AB meetings, both very productive and the AB members are actively engaged. The collaboration of the AB members has been instrumental in all phases of the project. They have made major contributions and have provided helpful insights about their businesses, organizations, and agencies.

Summary and Future Directions

The vision of the CPACE project is to revitalize undergraduate computing education within the engineering and technology fields to strengthen the engineering and technology enterprise of this country so it can compete in the global economy. Our objective is to design and implement a process to engage stakeholders from multiple sectors to identify engineering computational problem-solving skills, define how these skills can be integrated across curricula, and revise the curricula to integrate computational problem-solving directly informed by industry needs. We believe this process can serve as a model for national efforts to revitalize undergraduate computing education in engineering.

To meet this vision, we brought together faculty and administrators from Michigan State University (MSU), Lansing Community College (LCC) and – through the Corporation for Skilled Workforce (CSW) – leaders from business, industry and professional organizations in the region, who have an interest in transforming undergraduate computing education. We created and implemented a highly collaborative process to engage these participants in dialogue, explore common interests, and identify promising practices around computing knowledge and skills for the engineering workforce.

Using survey and interview instruments we determined stakeholders' engineering use of computer technology and the computational skills needed in their businesses. Our findings on the general engineering themes are consistent with other research on engineering education[6,7]: a) employers place a high value on interpersonal skills such as communication, ability to organize and present data, and the ability to function in a team; b) critical and innovative thinking and problem solving are important attributes; and c) employers 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. Employers place a high value on the ability of engineers to understand both engineering principles and computational principles that allow them to use computational tools to solve engineering problems by moving between abstractions in software and physical systems.

At the time we are writing this paper we are still receiving and analyzing employee survey responses. Preliminary analyses suggest that employers and employees have similar views of the importance of specific computing skills and the role of computing in mission critical tasks.

Currently, we are working on phase II (Figure 1, nodes II and III). We are analyzing the results in terms of computing principles[2] and aligning those principles with computer science concepts[3] that are the foundation of the computer science discipline. At this stage we are designing a strategy to map the workforce problem-solving requirements onto the foundational computer science principles. We are developing a framework to identify opportunities for curricular integration between computer science concepts and the engineering curricula across all engineering departments. By the time this paper is presented we expect to be preparing a publication detailing this strategy.

Bibliography

[1] Lattuca, L. R., Terenzini, P. T., & Volkwein, J. F. 2006. Engineering change: A study of the impact of EC2000. Baltimore, MD: ABET, Inc.

[2] Peter Denning: Great Principles of Computing, Communications of the ACM, November 2003/Vol. 46, No. 11, p. 15.

[3] Jeanette Wing: Computational Thinking, Communications of the ACM March 2006/Vol. 49, No. 3, p 33.

[4] http://online.onetcenter.org/ O*NET OnLine was developed for the U.S. Department of Labor by the National Center for O*NET Development.

[5] www.transana.org

[6] Committee on the Engineer of 2020, Educating the engineer of 2020: Adapting engineering education to the new century. National Academy Press: Washington, DC, 2005.

[7] Educating Engineers: Designing for the future of the field. The Carneige Foundation for the Advancement of Teaching 2008.

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Appendix I

This is an example of a typical interview. The interviewee's responses are shown in indented quotation marks. (To maintain confidentiality, we have de-identified the company using bracketed words when necessary).

The interview begins by asking them to identify the company's main mission or what sets it apart.

> "Our mission is to drive sustainable growth through the power of our people and brands by better serving the needs of our consumers, customers, and communities."
> "Our vision is to be the [product] company of choice.
> "[Our] Company's vision and mission statements define our focus upon sustainable growth, our broadened definition of social responsibility and the true strength of our company - our people and our brands. Our Vision encompasses the full spectrum of our stakeholders including shareowners, employees, customers, consumers and communities. Our mission articulates where we are as a company today and where we wish to be in the future. Our vision and mission do not stand alone. They are integrated with our focused strategy and operating principles as well as the foundations of our business: our values, people and commitment to social responsibility. Our competitive advantage includes our ability to innovate across their equities, brands, and placement and distribution."

The interviewer identified two or three major themes and confirmed them with the interviewee. In this case "focus upon sustainable growth", "where we are as a company today and where we wish to be in the future", "our competitive advantage includes our ability to innovate" With these themes in mind we focused the conversation on the engineering issues and the challenges that they perceive in these key areas and in particular the role of computation and technology (Figure 2; *identify and confirm).*

Big engineering Challenges (Figure 2 B):

> "1) Lower installed cost with capital
> 2) R & D function comes up with a lot of ideas that are not economical
> 3) Organization expects the engineers at the research institute to be engineering technology experts and develop sustainable products and solutions"

Core jobs and skills/entry level jobs and skills:

> "Mechanical Engineers, Chemical Engineers, Bio-Systems Engineers, Capital Project Managers, Launch Project Managers, and [product] Technicians - All of these positions require a mechanical aptitude at the entry-level. Launch Project Managers are broad/complex engineering roles that require an engineer to be skilled in marketing, production, and logistics.
> [Our company] has not experienced any difficulty in recruiting any entry-level engineers/technicians; we find that we are able to attract and retain engineering staff at all levels. The only periodic challenges we have are recruiting individuals

that have 5-10 years experience for some of our more advanced engineering roles."

"We do not have formal assessments/screening tools; however we use internships as a pre-screening tool and assess team skills through a rigorous behaviorally-based interviewing process.

Computational skills are very important, but the following skills are equally important:

- Understand drawings and be able to visualize
- Systems design
- Ability to relate data to real life
- Open mind to doing things differently
- Ability to problem solve
- Ability to relate to and work with others (i.e., interpersonal and team skills)
- Understand engineering theory and how to apply in real life
- Advanced Excel"

Role of Technology and computation (Figure 2 C):

"Engineering Computational software - Solid Works (usage rate 5-10%), Auto CAD, Process Data Analysis, Process Information, and Data Acquisition
Non-Computational Software- MS Office Suite (usage rate 25%) - Excel (especially advanced uses of it) and Word are big. E-mail/scheduling also big. These software tools enable staff to work more efficiently, communicate rapidly, and facilitate staff ability to work in a global work environment.
Training: Engage in a mix of internal and external training; however, [Company] provides in-house training on more advance computing skills."

Future of computation in engineering (Figure 2 D, E):

"We see the same positions mentioned previously being relevant and important 3-5 years out. We can envision that the expectations for these positions will be much higher, e.g., faster-better mentality.

The following skills are associated with these positions and will become increasingly important:

- Ability to stay on the leading edge of the industry and quickly adapt to new computational skills/tools
- Core computational skills that [our company] can leverage
- Ability to interface with diverse groups of people
- Ability to present data and information verbally and in writing
- Ability to "close the loop" when interacting with colleagues and clients (feel not all engineers can do this right now), that is see process/product/project through from beginning to end and how it fits into the big picture."

"See increase and intensive usage of: Excel, process modeling, scientific-based modeling, and heat transfer/chemical reaction software.

[Our company] is moving towards using more modeling software as the software becomes more and more efficient. They can't afford to take days to model something it is not cost effective. MATLAB will be used in the near future though not currently using it."

Appendix II

These are representative quotes taken from the interviews that illustrate the types of responses that fall within a particular general category.

Common themes 'general skills':

- Communication skills
  - "Effectively communicate about the information learned and decisions made in simple and easily understood ways that transcends cultural barriers."
  - "Skills like negotiation, asking questions, and conflict resolution. The ability to communicate to a diverse set of stakeholders such as colleagues, cross-functional teams, US clients, and International staff and customers is essential."
- Team work
  - "We assess team skills through a rigorous behaviorally-based interviewing process."
  - "Ability to relate to and work with others"
- Critical thinking
  - "Be able to question the data/information on reports or Figures generated by the software, and creativity in how to use the data and apply the computational tool/software"
- Innovative thinking
  - "Bring new ideas and ways to do something. Schools should be the most stimulating learning environment."
- Problem solving (both conceptual and operational)
  - "Critical to be able to identify issues and invent solutions."
  - "People need to be able to use ALL available technology"
  - "Even experienced engineers want to just crunch data but you need to be able to problem solve with the data that is available and make a decision and go forward"
- Ability to learn/adapt
  - "Need people who can respond to change right away. They need to have a flexible approach, be comfortable with ambiguity, and be independent."
  - "Balance: engineers need both focus and strength but need to be flexible to adapt and change with new challenges."

Common Themes 'computational aspects':

- Need basic computational skills. Job-specific skills can be picked up on the job.
  - "Things like ASPEN or statistical software don't care particularly which program because you'll learn that on the job depending on the business line the hire goes into."
- Understanding of principles, application and limitations of computational tools.
  - "Bottom line we want people who can think, do 'back-of-the-envelope' calculations and not depend on what the computer tells them."
  - "Need to align design constraints, manufacturing constraints, quality control constraints."

- Using technology to collaborate across/outside the organization. Using software collaboration tools.
    - "Internal communication within and across our 5 company locations has been a challenge, particularly when trying to find a 'trusted advisor' to share expertise and knowledge in a particular area in order to minimize staff energy spent on reinventing the wheel."
    - "We find ourselves doing a lot of internal training on web connectivity tools. They (engineers) have a general understanding of the functionality of the web as far as e-mail and IM and not much beyond that so sharing a file, centralizing information seems to be foreign"
- Use of technology to support broad problem solving and decision making.
    - "It is the conceptual nature of what they have to do that is more important. Need to be able to design a specific part and know how it works and make it so that it fits into the whole system or end product"
- Familiarity with multiple software systems, which may or may not share general operating principles.
    - "The key is knowing how to understand and read the data from the plant floor- understand what all the machines spit out. They need to be able to inter-phase with the machines, put it (the data) together and understand it. Also how to send data from one machine to another, then to a person, then interpret what the data means."
- Ability to move between abstractions in software and physical systems.
    - "Distributed Control System" This is the interface between the human and the process it represents a whole different computational level. It stores the data; engineers need to interact with this system and be able to apply statistical data analysis."
- Multiple CAD programs including 3-D modeling
- Process simulation packages
    - "There is a lot of modeling and simulation that we have to bring together from requirements to concept and performance analysis before we even begin to consider bending metal."
- Numeric computational platforms e.g. MATLAB, MATHCAD, Mathematica, MAPLE, POLYMATH
- Excel (High level capabilities)
    - "I would say workbook design--is an underutilized skill, the ability to intermingle worksheets into a comprehensive workbook."
    - "Use it as a way to check one's thinking and hypotheses; can run a quick macro or pivot table to think out an idea. This is a timesaver and a productivity boost."
- MS Office
- Knowledge of some programming.

Common Themes 'future of engineering practice':

- Corporate development, leadership, management skills. Project management software.
- Increasing integration of engineering data across larger systems (i.e., logistics & ordering).

- “Every company has some kind of accounting program that runs the whole company and engineers need to know how to operate in that environment”

- More business intelligence embedded in systems.
  - “Control system capabilities are very sophisticated for us need control system configuration and then tell that control system what to do to run the process more efficiently”
- Data Mining.
  - “How to get the data you need from all the information that is out there. Get the data you need to solve the problem you have”
  - “Used to be an issue not having enough data, now the issue is making sense of all the data we do have”
- Globalization, working with global timetables.
  - “Working globally across cultures, geographies and time zones, there is a need to have a common computational tools and language”
- Environmental impact across disciplines. Design for the environment (DFE).
  - “Sustainable, renewable big impact. Need talent that is not resident in company today.”
  - Will have to pay attention to what happens to product when it is in the field ‘designing for the environment’ DFE.”