Chemical Engineering Academia-Industry Alignment: Expectations about New Graduates

**An NSF-Sponsored Study
led by the
American Institute of Chemical Engineers**

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Executive Summary: Chemical Engineering Academia-Industry Alignment about New Graduates

How should chemical engineering graduates be prepared most effectively for their careers? To answer, we must achieve a degree of alignment among the expectations of academic and industrial chemical engineers. These groups can have important differences of opinion about what technical content and professional skills new graduates should have. The profession's diverse career directions require that in a deeper sense, we must also align the expectations of what chemical engineering is.

The present study builds on a 2013 AIChE plenary event on "Chemical Engineering Expertise in Academe and as Sought by Industry," chaired by the late John Chen. That event identified an expertise shift in faculty away from research in the traditional process sciences, largely toward activity in fundamental and applied biological sciences.

It left unanswered the question of whether this shift weakens or aids the effectiveness of ChE education for the breadth of industrial careers. Also, academics and industry differ in their perspectives on what parts of ChE education are essential and which are just desirable.

Here, academic and industrial chemical engineers were first surveyed, the latter group divided into senior (B.S. before 2001) and junior cohorts. This survey was analyzed by pooling statisticians and then by the task force who composed this report. It then was further digested and explored in a two-day industrial-academic workshop held March 9 and 10, 2015, at the National Science Foundation. To strengthen this resulting report, it was vetted among a broad set of readers.

Key findings and recommendations of this study build on changes in the technologies of chemical engineering and education, the profession, and its place in the world. Nevertheless, many findings echo longtime issues.

- The **ChE undergraduate** core-topic structure (balances, thermodynamics, transport, separations, kinetics, and design) has endured not because it is frozen but because it has adapted dynamically to new ideas, emphases, challenges, and opportunities.

> *"I only use about 10% of what I learned in college, but the ChE program teaches you how to learn and the process to learn new things. When you get to your starting job, you can learn whatever information needed without difficulty. College gives you the building blocks." –Junior industrial*

  - Industrial voices asserted that academics should provide still greater technical breadth of topics. At the same time, depth is necessary in central, foundational topics.
  - Learning biochemical principles now is generally accepted and desired by industry as a ChE fundamental. It should be woven better into the core structure.
  - New emphasis is particularly needed on process safety, applied statistics, process dynamics, and applied process control through new teaching materials and effective integration into the curriculum.
  - Re-emphasis is needed on actively developing communications skills, especially writing; critical-thinking skills; leadership and team-function skills; open-ended task analysis and problem solving; and time management. Passively expecting such skills to develop is inadequate.
  - Getting professional experience in co-ops, summer jobs, and international contexts has increased in importance.

> *"Never underestimate the importance of soft skills. Solid technical fundamentals are the basis for the job assignment. Soft skills are what differentiate you." - Industrial*

- Terminal **master's degrees** can add valuable depth, but the individual must weigh their benefit vs. cost.
- **PhDs** usually transition smoothly into industrial positions when their doctoral research and first job are closely related, but their career development requires breadth.
  - Pre-graduation professional development would be very valuable for PhDs, whether they enter or interact with industry. PhDs should be better prepared to adapt to industrial work environments and communication styles.

> *"What I was missing for my job in industry was the perspective a commercial organization takes on research vs. a university. I'm not sure that my PhD research would ever be able to prepare me for that." – Junior industrial*

  - Students from non-ChE disciplines entering ChE PhD studies need effective exposure to and strengthening in the breadth of core chemical-engineering topics.
- **Faculty members** all bear responsibility to have a sound, sufficiently deep perspective on the core curriculum.
  - Having some industrial or consulting experience results in faculty members who are better able to give perspectives on application of the core ChE topics.
  - At the same time, faculty attitude is most crucial for framing a topic's technological context effectively -- being open and inquisitive about the specific content and its context, the broader curriculum's diverse topics, their connectedness, and their applications. Teaching core courses and being aware of the broader curriculum's topics should be an expectation for faculty members both with and without prior ChE backgrounds.
  - Faculty members need good teaching materials but also need good instruction on how to teach effectively with new material and with new teaching technologies.

> *"Don't confuse education and training." - Academic*

- **Industry** is a key partner in preparing students to be effective employees by providing co-ops/summer jobs, collaborating in research, hosting grad-student internships, and seeking/hiring faculty for summers and sabbaticals.
- **AIChE** should actively use its programming and AIChE Academy to expose students to industrial aspects.
- **Government** can encourage advances in education through balanced research and educational funding.
  - Research funding for chemical engineering academics should balance process and product sciences through base programs and through new initiatives.
  - For advancing changes such as are proposed here, government decision-makers want to have joint industry-academic thought leadership.

Chemical Engineering Academia-Industry Alignment: Expectations about New Graduates

Introduction

How should chemical engineering graduates be prepared most effectively for their careers? At that question's root, what is the discipline of chemical engineering? There are diverse opinions about both questions because chemical engineering careers and applications are so diverse.

These questions are vital both for undergraduates and for graduate students. They are vital to how faculty members should educate and to how they themselves should be prepared. They are vital to the interests of industry, professional societies, and government and for shaping their influences on academia. They are vital to what we define as the core topics of chemical engineering. Finally, they are vital to the breadth of chemical engineering as graduate students and faculty enter from talent pools outside ChE backgrounds.

To preparing students most effectively, it is important to explore and to seek alignment between the expectations of faculty members who educate students and employers who hire them. The goal is insight that will aid the content and style of chemical engineering education.

Engineering disciplines are not defined solely by the industries they serve or roles their graduates play. One example is that a chemist or a biologist or a physicist or a mechanical engineer might be very effective in typical chemical-engineering tasks.

Rather, engineering disciplines are best distinguished by the scientific principles they most centrally rest on. In general, engineers apply systems approaches to create technological advances and to solve practical problems. Engineers draw from the expertise and experts in whatever scientific principles are required for the task at hand. However, focusing on a specific domain of science – such as electromagnetism (electrical engineering), the intersection of mechanics and geoscience (civil engineering), or nuclear physics (nuclear engineering) – develops a body of knowledge and individuals providing focused expertise.

The foundational science that defines the discipline of chemical engineering is *molecular science* -- chemistry, materials, and now biology. The substance of the discipline is defined by applying this science to processes and products through fundamental tools of conservation equations, thermodynamics, kinetics, and transport to processes and products, directly or indirectly, in industries as diverse as fuels, polymers, pharmaceuticals, health care, food, microelectronics, and paper. Using this framework, it is easier to consider the present and ideal approaches for preparing chemical engineering graduates.

Origin and approach of this study

The present study builds on a 2013 AIChE plenary event on "Chemical Engineering Expertise in Academe and as Sought by Industry," chaired by the late John Chen. That event identified an expertise shift in faculty away from research in the traditional process sciences, largely toward fundamental and applied biological sciences. It increased interest in examining how academics and industry differ in their perspectives on what parts of ChE education are essential and which are desirable. It also left unanswered the question of whether this shift weakens or aids the effectiveness of ChE education for industrial careers.

A small group of industrial and academic thought leaders met in January 2014 meeting at AIChE's home office, led by William B. Russel of Princeton and Ignacio E. Grossmann of Carnegie Mellon. A task force was created to compare and contrast the perspectives of academics and industrial chemical engineers on how undergraduates and graduate students should best be prepared for their careers. Technical and nontechnical skills were to be considered. Also, faculty preparation was acknowledged as a growing point of concern as more non-chemical engineers join faculties of chemical engineering departments.

The approach was a National Science Foundation-funded survey on these issues, followed by a workshop at NSF. Some survey questions were common for all participants, while other questions were directed separately for three cohorts: Academics, senior industrial staff (B.S. before 2001, or approximately age 35), and junior industrial staff (B.S. since 2001). This survey was analyzed by a small task force and further digested and explored in a two-day industrial-academic workshop held March 9-10, 2015, at the NSF. The study has also drawn from recent reviews of trends in the chemical engineering profession and education.[1,2,3] The task force has analyzed the findings, proposed recommendations, vetted them among a broad set of chemical engineers, and summarized them in this report.

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[1] P.R. Westmoreland, "Chemical Engineering in the Next 25 Years," *Chemical Engineering Progress* **104**(11), 30-41 (2008).

[2] P. R. Westmoreland, "Opportunities and challenges for a Golden Age of chemical engineering," *Frontiers of Chemical Science and Engineering* **8**(1), 1-7 (2014).

[3] A. Varma, I. E. Grossmann, "Evolving trends in chemical engineering education," *AIChE J.* **60**(11), 3692–3700 (2014).

Context: Present status and the future of chemical engineering employment

Chemical engineering employment has always offered diverse paths. Industry employs by far the largest number of graduates. Industrial roles include manufacturing, development, commercial, management, and support, while some graduates become faculty, physicians, attorneys, financial analysts, politicians, or specialists in other disciplines. In the last 50 years, there have been dramatic shifts among technical paths.

From World War I until the 1990s, chemical production processes dominated industrial hiring, led strongly by oil and petrochemicals. As late as 1991, 63% of chemical engineers entered fuel and chemical companies. However, by the 1980s, the hottest areas of academic research had begun to be materials and bioscience.

The most advanced U.S. academic research in chemical engineering began turning toward fundamental science

and away from process science and manufacturing processes, particularly after World War II. One factor was the high status of science. Another was the increasing power of mathematical physics, eventually aided by access to computers. Yet another was that companies and their corporate research centers encouraged academics to focus on science, as opposed to process development. Companies expected that they would then convert this academic science into new processes and products.

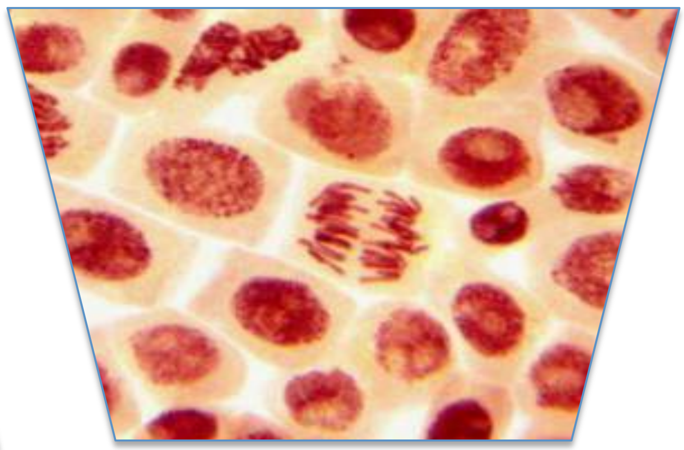
Meanwhile, product science and engineering was growing to new importance within chemical engineering in the 1980s. ChE academics began to be much more involved in material science and engineering. An example is how chemical engineers helped shape the concepts and applications of nanotechnology.

The same period saw dramatic advances in the understanding and application of bioscience. Identifying and modifying the chemical mechanisms of molecular biology brought about the founding of companies like Amgen, Biogen, and Genentech, based on genetic engineering of biologics. Initially, chemical engineers were involved mainly with bioreactors, separations, and production. As biology has become more thoroughly anchored in chemistry, academic chemical engineers have become deeply engaged in bioscience and biomedical science.

In 1988, leaders in the profession predicted that the future directions of chemical engineering research were changing away from oil and petrochemicals:[4]

1. Biotechnology and Biomedicine
2. Electronic, Photonic, and Recording Materials and Devices
3. Polymers, Ceramic, and Composites
4. Processing of Energy and Natural Resources
5. Environmental Protection, Process Safety, and Hazardous Waste Management
6. Computer-Assisted Process and Control Engineering
7. Surface, Interfaces, and Microstructures

Some of these topics were relatively new to chemical



engineering but are common now, often with new aspects.

Hiring also seemed to reflect this shift from oil and petrochemicals. The number of chemical engineers entering fuel and chemical companies had dropped to 41% by 2000.

Now consider the changes we see today. The futures of new graduates will be shaped by these changes, and their preparation must be shaped accordingly. Some changes are resource-driven, as described below. Others have been driven by rapid advances in biosciences, analytics, and perhaps most of all by information access through Internet apps and the Web, which did not exist in 1988. Computing power and connectedness are available even as we walk around.

Consider some specific fields and changes:

[4] Committee on *Chemical Engineering Frontiers: Research Needs and Opportunities*, National Research Council, “Frontiers of Chemical Engineering: Research Needs and Opportunities,” National Academy of Engineering (1988).

- **Oil and gas** have dramatically shifted the energy and petrochemicals picture from scarcity to abundance, largely due to “unconventional oil and gas”: Deep reserves recovered through directional drilling combined with hydrofracturing. This shift has put pressure against sustainable biofuels and other renewable energy resources for price-point reasons.
- **Chemical manufacturing** in the United States is back as a key part of the global manufacturing industry after it had been considered to be on its way out of the US in the 1990s. Abundant gas and oil have reduced the cost of energy for the general economy. Raw-material costs for chemical production have also been reduced along with energy costs. Developments in specialty chemicals, bio-derived chemicals, and fossil-hydrocarbon-based chemicals all contribute.

- **Renewable power** has been growing worldwide at a 27%/yr rate, while near-term prospects for US **nuclear power** have diminished due to the nuclear-reactor disaster at Fukushima Daiichi, high capital costs, and unresolved nuclear waste disposal.
- **Sustainability** includes financial viability, but it has grown to mean more: Assessing company performance using a “triple bottom line” of financial, social and environmental performance over a long period of time. Chemical engineers are particular experts in improving environmental performance. **Carbon management** is anticipated to become routinely part of continued fossil-fuel use. Sequestration of CO_2 will likely driven toward using CO_2 as a carbon source. Another sustainability dimension is the **energy-water-food nexus**. Food is a worldwide necessity that requires water for its production; at the same time, 35% of US water use is for power generation. This competition presents a societal need that calls for technical advances.
- Chemical engineers are increasingly key players in **applied bioscience** like development and production of pharmaceuticals, bio-based chemicals, and biomedical devices. Applied bioscience calls on many disciplines, but as it has become more of an applied molecular science. The roles of chemical engineers have expanded to the point that biology is now widely regarded as a foundational discipline for modern ChE. In 1988, genetic manipulation was still shifting from evolutionary methods to gene splicing. Now synthetic biology and CRISPR-Cas9 methods for gene modification are becoming practical tools to make new substances and organisms. These approaches and others like systems biology and bioinformatics draw on many chemical-engineering skill sets.

Student experiences have changed, too. During the course of their studies, they come to take for granted that their classmates and teams and future employers are multicultural and international. They are at ease using programs or apps on varied computer platforms, but they are less savvy than before about how those apps work. They continue to struggle with effective writing, but computer tools help them be much better in oral presentations. How can educators best prepare them for their diverse careers and the changes those careers will undergo?

Survey and workshop participants contended that certain ChE fundamentals make up the basis for continually updating and adding to BS, MS, and PhD education that is sound and relevant to industry. At the same time, they note changes that will improve chemical-engineering education: Changes in content, in balance, in faculty approaches, in industry engagement, in professional societies’ support, and in government policy. These findings are detailed in the following section.

Findings

The findings address the present status of chemical engineering education and its results. They are divided into seven broad categories:

(1) Preparation of undergraduates for industrial careers
(2) Preparation of M.S. students for industrial careers
(3) Preparation of Ph.D. students for industrial careers
(4) Preparation of faculty for the core curriculum
(5) Roles of industry in aiding effective preparation
(6) Roles of professional societies in aiding effective preparation
(7) Roles of government agencies in aiding effective preparation.

(1) Preparation of undergraduates for industrial careers

Undergraduate preparation is the core issue, as it is the foundation for being a chemical engineer. We expect that students will learn scientific and technological concepts, tools to translate the concepts into practice, and styles and approaches to aid their practice of the profession.

(1.1) Preparation through the core curriculum

The current ChE undergraduate structure of core topics is:

- Material and energy balances
- Thermodynamics
- Transport: Flows, Heat transfer, Mass transfer
- Separations / Unit Operations
- Reaction kinetics and engineering
- Process design and control

These topics are supported by ChE laboratory experiences, a capstone design project, and often courses in process dynamics and control and in math and computer methods for chemical engineering. Students usually also have coursework in calculus and differential equations; general principles of chemistry, organic chemistry, and sometimes physical chemistry and biochemistry; physics; and liberal arts. Within the full curriculum, they may have some choice of cross-disciplinary technical and free electives, possibly conducting faculty-supervised research and/or satisfying a concentration, minor, or bachelor's thesis.

The combination of core ChE technical topics has endured not because it is frozen but because it has adapted dynamically to new ideas, emphases, challenges, and opportunities.

> ***Fundamentals take us into the future.***
>
> *"We must make sure they can do the analysis and application for separations and other processes that do not yet exist." – Senior industrial*
>
> *"The biggest thing is the fundamental concepts. If you are designing a new unit, you will likely be a part of a team with at least one experienced engineer. While the final-stage particulars will need to be established with more complicated models, the fundamental exercises (i.e., McCabe-Thiele analysis) can tell you a lot of information up front to guide the design. If you are in production like myself, there are a lot of resources available to deal with the particulars of your operation. Yet here again, the fundamentals are the guide. One of the big trends we look at in our morning meeting is Reflux Ratio!" – Junior industrial*

These changes are perceived differently by different people. The differences notably depend on their proximity to the educational process, time since they were in school, and experience with newly graduated ChEs. Industrial ChEs often have different perspectives due to particular applications and experience compared to academic research directions.

Still, industry and academia generally agree on common elements of a chemical-engineering curriculum. Survey and workshop participants emphasized that to remain vital, both the core topics and their new dimensions must be incorporated.

External and internal factors both drive gradual shifts in the chemical engineering curriculum in the United States. Academics seek external input from ABET stakeholders, such as alumni surveys and departments' Industrial Advisory Boards. The number of credit hours is limited by the four-year standard and the accompanying financial expectations, and it is often determined by institutional administrators or state governing bodies.

An important curriculum-change effort by the broad chemical engineering community was the 2003-2005 "Frontiers in Chemical Engineering Education" project[5] led by Bob Armstrong of MIT. Key recommendations from this work included shifting to a paradigm built on molecular transformation, multi-scale analysis, and the engineering systems approach. The approach suffers from a lack of current textbooks, of any requirement to revamp the core significantly, and of funding to carry out such a change. Consequently, the approach has had limited implementation.

(1.2) Preparation through the changing curriculum

Change is going on, nevertheless. Many changes are school-specific, such as development of specialty electives or incorporation of useful examples from new technologies.

Several broader trends were identified and are summarized here:

- Biomolecular engineering,
- Formal process-safety instruction,
- Statistics and analytics,
- Computing apps / tools,
- Decreased process dynamics and control,
- Sustainability as a design principle,
- Integrated product-process design,

[5] http://web.mit.edu/che-curriculum/

- Integrating soft skills,
- Decreased faculty experience with industry and even with core topics.

Biomolecular engineering is now generally woven into undergraduate chemical-engineering coursework through examples, as opposed to being taught as separate, core chemical-engineering courses. About 68% of ChE programs report incorporation of biological systems into their material and energy balance courses,[6] and mass transfer and kinetics provide other natural opportunities. However, many programs still do not require any preparatory biology courses.

A different biotechnology concern expressed by an industrial participant in the workshop was, "Students are not really being trained at scale. Exposure to fundamentals, but we're not investing in the infrastructure to do bioprocess development well." There are exceptions that provide useful counterexamples. The Biomanufacturing Training and Education Center (BTEC) at North Carolina State University uses GLP/GMP pilot-scale production equipment to support a B.S. degree concentration in Biomanufacturing, as well as graduate studies and a certificate program.[7]

> ***Process safety must be a part of the curriculum.***
>
> *"Reactivity and safety systems are so important today. I wish my Bachelors degree program had introduced us to industry codes and safety standards (OSHA, API, ASME) as well as process-safety analysis techniques. It's especially valuable to have exposure during the design course to what a Process Hazard Analysis is and how it will improve a system's safety." – Junior industrial*
>
> *"Chemical engineering undergraduate programs must include mandatory courses in environmental and safety rules and regulations, as well as ethics. There are way too many chemical engineers in industry that are clueless about EPA and OSHA requirements, do not understand the long-term consequences of their actions, and try to find away around them because of either 'time' or 'costs'." – Senior industrial*

Process safety is becoming academic priority, but successful inclusion requires reaching deeply into the curriculum. Personal lab safety has always been emphasized, but education in process safety has been largely deferred to industry. Industrial participants expressed particular concern about the lack of a "safety culture" among chemical-engineering graduates without work experience.

That is one reason for the recent modification of ABET Program Criteria in chemical, biochemical, biomolecular, and similarly named engineering programs. It requires that curricula "include the engineering application of these basic sciences to the design, analysis, and control of chemical, physical, and/or biological processes, including the hazards associated with these processes."

Most engineers have to deal with safety issues early in their careers, so learning about with specific process-safety training concepts is important area to add to the curriculum, including Environmental Health and Safety hazards and issues, HSE / OSHA / PSM issues (including fault-tree and risk analyses). This content is very helpful for quality control and company risk management, also.

ABET compliance seems to be increasing the safety-education content of chemical engineering programs, but its impact on a "safety culture" may be inadequate if content is not integrated throughout the core curriculum. A recently updated textbook by Crowl and Louvar, *Chemical Process Safety*,[8] is finding use. Safety-instruction modules that also qualify students for safety certification are being distributed by SACHE, an education-focused affiliate of AIChE's Center for Chemical Process Safety (CCPS). Certainly, process and product safety topics are necessary in the capstone design sequence.[9] Some schools introduce Environmental Health and Safety methods such as fault-tree analysis.

> ***Using statistics and analytics has become vital.***
>
> *" If there is one skill set that is commonly learned once on the job, I would say it is statistics/data analysis. This is generally taught in-house, as coursework appears to be light on this." – Senior industrial*
>
> *"This is a long-term problem – I've seen these discussions 30 years ago – but what's changed is that it's a requirement to have statistics and to design and interpret data. You're missing a fundamental skill set." – Senior industrial*

Statistics and analytics (using statistics for decision-making) have also emerged over the past decade as essential skills for chemical engineering graduates. Industry often has to train new hires in the fundamental statistics required to apply lean manufacturing and quality-control methodologies. ChE departments are now incorporating a higher level of statistics into their curricula. Industrial representatives expressed a desire to see a more uniform level of statistical competency amongst new hires. Six Sigma and related statistical methodologies are only reported in about 21% of capstone design sequences.

In many cases, a junior engineer can make a significant difference in a company by applying simple statistical design and analyses to a process, process-step, quality-Improvement, or process-improvement effort within a company. Thus, familiarity with DOE (statistical design of experiments) and continuous-improvement techniques could be very helpful preparation for a new engineer entering industry.

Computing apps / tools are the focus of ChE computing education. Excel is reported as used in essentially all programs. Computer algebra systems (CAS), software programs that facilitate symbolic mathematics, are used 33% less frequently compared to spreadsheets in the sophomore material and energy balance course and half as often as spreadsheets in the capstone design sequence. Very few programs require computer programming outside of CAS

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[6] D. L. Silverstein, L. G. Bullard, M. A. Vigeant, "How We Teach: Material and Energy Balances," Proc. of the 2012 ASEE Annual Meeting, June 2012.

[7] http://www.btec.ncsu.edu

[8] D. A. Crowl, J. F. Louvar, *Chemical Process Safety, 3rd Ed.*, Prentice-Hall, 2011.

[9] D. L. Silverstein, L. G. Bullard, W. D. Seider, M. A. Vigeant, "How We Teach: Capstone Design," Proc. of the 2013 ASEE Annual Meeting, June 2013.

> ***Simulation is used heavily in some careers.***
> *"The undergraduate and graduate degree I obtained offered no preparation in simulation. It was optional for students to pick up in their 'spare time' and apply to the course work as they saw fit. In summary, nobody used it and we were unprepared for industry where everyone uses some type of simulation software." – Junior industrial*
> ***And computers are omnipresent but not omniscient.***
> *"Many of the hired engineers were too reliant on computer tools and blindly accepted the output from the tools without thinking critically." – Senior industrial*

software like MATLAB. Most chemical engineering departments do use process simulation software, but it is typically limited to steady-state simulation.

There is discontinuity between computing skills of new graduates and what is desired by industry. Academia often has the benefit of modern software in use by industry (such as process simulators and statistics) available at low cost, but faculty often lack the expertise to use it at a level which facilitates effective instruction. Industry often has little interest in the software that many faculty members do teach well, such as advanced math software. There is a particular need for training faculty for using process-simulation software for industrially relevant analyses.

> ***Expectations conflict strongly in process control.***
> - *"We prefer to hire Chemical Engineers with a strong understanding of 1) process control for system design and operation and 2) statistics for data analysis/evaluation." – Senior industrial*
> - *"Instrumentation and control systems are not really covered in the UG curriculum." – Junior industrial*
> - *"The hardest course to staff is Process Control because it is not seen as a viable funded research area. Few newer faculty have had exposure to process control beyond the basic undergrad course; non-ChEs have often had no exposure or interest at all." – Academic*
> - *"An even bigger need is dynamics. New graduates need an ability to jump between scales, from the molecular to the continuum, from lab to pilot to process, and to manage product scale-up, steady state and the dynamics." - Industrial*

Better practical understanding of process control and of dynamics was cited strongly by industry as a part of preparation where new employees need to have a better grasp. At the same time, courses on process dynamics and control are being eliminated, or material is being shifted into the laboratory or design courses. Much of the academic discussion of the control curriculum is over the extent and level of process-control theory. Industry asks for giving more weight to the translation of this theory into implementing control of processes.

A concern expressed by academics was that it is hard to justify using a whole position to hire a single faculty member to teach control, especially when research funding in the area is so limited. The response by industry was twofold. First, there was acknowledgment that education about the practical aspects of implementing control theory is a key place where industrial engagement with faculty would be valuable. Second, industry opinions were that there should be more emphasis on dynamics in the curriculum. The "control course" is also predominantly where modeling and understanding of dynamics are taught.

Sustainability as a design principle (assessment against a combined financial, societal, and environmental bottom line) has gained ground as a core topic in design courses, and sustainability is an ABET-expected consideration in design projects. Sustainability or life cycle analysis was cited by about 27% of ChE programs as part of their capstone design sequence, and 45% reported sustainability as a topic. The AIChE Sustainable Engineering Forum is leading and effort to bring an industrial perspective on sustainability into the chemical engineering curriculum.

integrated product-process design is included in the undergraduate curriculum, and it seems very important for future innovations. There are examples of product design courses (Michigan has a product-engineering course with a lab), and there are product-design textbooks by Wei[10] and by Cussler and Moggridge.[11] About 40% of surveyed ChE programs report they include product design as a topic in their capstone design sequence, up from 35%.

> ***Having both technical skills and non-technical skills is essential for advancement.***
> *"If I were just starting out my career today, I would have focused earlier in my career on soft skills. My first jobs were very technical, and so were the skills that I needed to accomplish them. But as I moved from technical to management, I needed softer skills, such as management, leadership, presentation, and influence without authority. I believe it is best to have these skills before you need them." – Senior nonacademic*

Non-technical skills – "soft skills" -- are of continuing concern to industry. Soft skills remain important, but critical-thinking and communications skills are usually not taught directly. Again, ABET criteria require that a program demonstrate that its students achieve a satisfactory level of competence in these (and other commonly grouped) skills. Because the level of achievement required depends on individual program targets, the ABET baseline only assures they are addressed to some degree, not necessarily to a level desired by industry.

The chemical-engineering laboratory course typically contributes to outcomes desired by industry like safety, troubleshooting, teamwork, written and oral communications, and critical thinking.

> ***It helps if faculty are knowledgeable about practice.***
> *"When in school, I had a single professor with prior industry experience. That was the one who could best relate our coursework to real work application." – Junior industrial*

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[10] J. Wei, *Product Engineering: Molecular Structure and Properties*, Oxford Univ. Press, 2007.

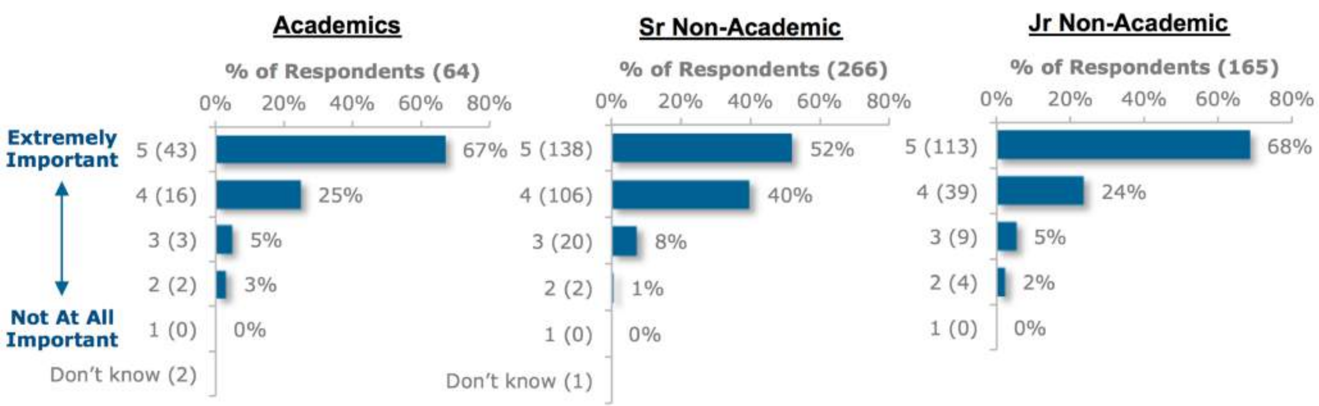
[11] E. L. Cussler, G. D. Moggridge, *Chemical Product Design*, Cambridge Univ. Press, 2011.

Finally, there is **decreased faculty experience with industry and**, in the case of faculty members who come from non-chemical-engineering backgrounds, **limited experience with core topics**. At the heart of this concern is the question of how it affects student preparation. Many industrial participants thought this change was a critical problem, while many academics saw it less important because the teaching priorities should be on fundamentals.

Ultimately, the central issue for student preparation in fundamentals is making the necessary connections between descriptions/equations and the physical realities of the phenomena and their applications. The broad feedback from industry was to **emphasize the fundamentals**, aiming for new graduates to have both conceptual and physical understanding, plus specific useful problem-solving skills and insights into key applications and the breadth of needed professional capabilities. Industrial voices asserted that academics should provide even greater technical breadth of topics, sacrificing depth about some topics while ensuring that students dive deeply into selected foundational topics and applications.

(1.2) Preparation through workplace experience

Academic and industrial participants agreed: It would be ideal for new graduates to be completely prepared for whatever employment they might take. The reality is that chemical-engineering employment is quite diverse. Also, additional specific education must happen in the workplace.



Nearly all respondents considered practical experience (e.g., internships, co-ops, prior technical jobs) to be important for chemical engineering BS/MS graduates.

Part of the additional preparation is in learning and adapting to how a given company or industry or work location operates. Students who begin with military or other considerable life and work experience have a head start. New graduates often struggle to learn that how you work and how you communicate it is as important as the work you do.

Application of the students' fundamental knowledge to practical industry issues and problems such as process control, process / product safety, innovation approaches, and entrepreneurial skills is often missed by the industry-bound engineer. Thus, many of the suggested changes to the academic curriculum focused on ways to better apply the engineering fundamentals to real-life engineering situations and problems.

Technical preparation beyond the university takes two major forms. First, a classic way of making the connection between ideas and workplace application is for students to do **co-ops or summer jobs**. This topic was a major discussion point in the open comments within the survey and in the workshop. The other approach is **education and training after starting employment**. This preparation is a mixture of mentoring, self-study, and formal training. It may be provided by company policy, through the initiative of supervisors or colleagues in the company, or through being sought out by the employee.

First consider co-operative education or "co-op" positions, along with shorter summer jobs and internships. Co-op programs require students to be absent from the university, spending their time working at a company for one or more (typically 3-5) semesters, generally not consecutive. The student takes on pre-professional and professional roles, receiving salary and university credits. Supervision is by an employee and by the university's co-op office.

The positive experience of co-ops has been documented, for instance in Forbes magazine.[12] Aside from exposing students to real-world problems, co-ops have the advantage of providing a significant source of income to the students, which greatly helps them to face the ever-increasing tuition charges by universities. At the same time, participation in a co-op program extends the time to graduation.

Summer internships are similar to co-op programs except that their duration is between academic semesters and generally do not extend the time to graduation.

In an informal survey from about a dozen universities, it appears that by the time of graduation, about 50-60% of the students have participated in co-op or summer internship programs.

[12]http://www.forbes.com/sites/troyonink/2012/02/27/why-college-co-op-programs-totally-rock/

Co-op: Is it necessary? There were differences of opinion about whether a co-op is a necessity. The point of agreement was that however they achieve it, new graduates should have a firm grasp of the concepts and their applications, and they must acquire a realistic sense of context and how the concepts apply.

Young professionals and new-hire supervisors emphasized the value of pre-employment practical experience for BSChE graduates. Companies are definitely more likely to hire chemical engineering graduates who have completed successful internships, co-ops, or other technical jobs.

Most of the survey's industry respondents strongly support supplementing the academic training with work outside the classroom in an industrial environment. Of the industry respondents to the survey, 81% gave a 4 or 5 (5 max) to the importance of internships or coops when hiring new employees, compared to 37% of the academic, but nearly all (92%) respondents (academic, senior non-academic and junior non-academic) found practical experience to be very or extremely valuable for BS/MS graduates. The majority (81%) of senior non-academic respondents responded that they are more likely to hire someone if they had practical experience.

Some companies see it as a hiring requirement, not just an advantage. At the same time, there were survey respondents from both junior and senior industrial categories who felt pre-graduation practical experience was not necessary because of graduates' on-the-job training.

Pre-graduation experience: Valuable or essential?

"Graduating engineers lack actual design and practical experience without being involved in a co-op or internship. Having the practical experience is key." – Industrial

"At DuPont, we don't hire people without internships, so we provide internships and co-ops. We see the internships as a critical piece of the translation from fundamentals to applications." – Senior industrial

Co-op: What is its value? Clearly both co-op programs and summer internships provide valuable experience to the students. More importantly, they often help secure placement of the students since companies have the opportunity of assessing their performance without committing themselves to hiring the students. In that sense, co-op programs and summer internships can be viewed as win-win propositions.

It is clear enough why such experience is beneficial. Co-op and summer students are faced with adapting to industrial application of the knowledge and thinking skills they have been developing in school. Of the graduates who received this work training, over 90% said that it was extremely valuable or a very valuable experience because the work focused on real-life problem solving during their industrial experience, internships, co-ops, and post-docs.

More subtly, these students develop a more balanced appreciation of how they must manage their workflow and interactions with others in the workplace. More than that, they are taught the skills and styles of the particular company they are working with. If they eventually are employed by another company or in another field, the perspective they have gained can be a powerful basis for improving within their new contexts.

The value is grasping industrial work processes.

"Co-op experience really bridges the gap between theory/classroom lectures and real world applications. Depending on the route you take, having the connection of real-world application to lecture material can motivate you to trying harder to retaining the lecture material (making the grade) while going through college." – Industrial

Co-op: Should all students do it? At the heart of this question is the discrepancy between academic and industrial opinions. If all students were required to have some industrial experience, it would avoid the problem of graduating chemical engineers who have no first-hand knowledge of the industry, whether in the more traditional process industries or in pharma, biotech, or electronic materials.

Academics do not feel there is as much need for pre-graduation workplace preparation as industrial participants, asserting that their role is the general preparation for a career rather than the preparation for a specific job. There was support for this idea from many workshop participants from industry. The majority (71%) of surveyed academics felt that their undergraduates are extremely or very prepared for the positions for which they are hired. They recognize that new graduates will have job-specific training by their particular employer and industry, driven by the diversity of possible employment directions.

It may be desirable that all students have co-ops and summer jobs, but there aren't enough positions.

"Our BS/MS graduates attend our mandatory co-op program and are often cited by employers as being 'able to hit the ground running.' However with increasing undergrad enrollment, it becomes increasingly more challenging to place all students, especially the lower end of the class and international students. Students who are tracked into faculty research labs for this experience don't get the same exposure as the top of the class." - Academic

Except for few schools, there is a perception that the numbers of co-op students is experiencing a decline while the number of summer internship student seems to have increased somewhat. Four major reasons are the following:

1. For universities, scheduling usually makes it more difficult to offer co-op programs. Courses may have to be offered in both semesters. The small size of most US chemical engineering departments restricts courses to be offered only once per year. Alternatively, course sequences for co-op students can require using two consecutive semesters. In either case, there is no room for error or academic difficulties.
2. Setting up the placements and monitoring their educational effectiveness also requires substantial resources from the academic institution. Summer positions usually do not involve the university.
3. For companies, coordinating co-op programs is somewhat more complex than summer internships, which can be more easily streamlined. However, a three-month internship seldom provides sufficient time to educate an undergraduate to produce meaningful data in many cases. A six-month co-op can provide

meaningful experience to the student and meaningful and useful work to the company.

4. Companies have a limited number of positions, too few to accommodate all students. A few institutions require their students gain industrial experience through an internship or formal co-op, but expanding such requirements more broadly is challenging due to limited industrial opportunities, particularly during low points in the economic cycle.

Thus, few academic institutions require workplace experience for B.S. graduation. Only 12% of the surveyed junior industrial respondents were required to complete practical experience as part of their degree program. Most academic departments see it as beneficial but not necessary. Industry generally acknowledges these practical issues, and large companies provide funding for sufficient co-ops and summer positions to meet projected hiring needs.

> ***Work experience trumps international experience:***
> *"We have seen a move to promote International Studies over internships. We will hire those with experience in industry over International Studies – period! – and I have had lengthy debates with deans who disagree." – Senior industrial*

Co-op vs. international experience. A related topic that was discussed was the importance of international experience as the global economy becomes more interconnected. Widespread industrial uses of operational teleconferences across many time zones and multi-site workgroups illustrate the need for language skills and cross-cultural awareness. Study-Abroad programs appeal to many students who want to travel and have in-depth life experiences internationally.

However, industrial participants stated that they give higher value to the workplace experience of developing conceptual connection between academic fundamentals and practical applications. The general opinion was that international experience as an undergraduate is indeed broadening and valuable but not crucial.

An interesting alternative model is conducting design projects with internationally mixed teams. This approach has been carried out between Texas A&M's campuses in College Station and Qatar. Work is divided, and team members meet and are reviewed using Skype, Google HangOut, or suchlike.

Students do need to understand that such interactions are increasingly common. It is important for the educational experience to cultivate open attitudes to different cultures and social mores in a diverse workplace.

Providing pre-employment experience within the college experience. Besides co-ops and summer jobs, very useful practical experiences may be provided by collaboration with industry to provide real-world problems and projects in courses. Other useful contacts with the workplace are use of current, industry-relevant case studies, exposure in seminars by industry, tours of industrial plants, and using adjunct faculty from industry to teach courses. It was discussed that the best practices in industry should be shared with academia, such as maintaining a culture of safety. These approaches are helpful even though they do not provide immersive, in-the-plant experience. For other types of industrial employment, they may be quite realistic.

Incorporating of professional mentoring early, even as part of the academic experience providing real-world examples of problems, may be beneficial. Similarly, providing the opportunity to learn about a small technical area, independently, as part of the academic training, could be very helpful to one considering entrance to rapidly changing spectrum of industrial chemical engineering positions.

> ***Job-specific preparation is inevitable.***
> - *"It's always nice to have skill sets coming to work, but many jobs are pretty specific on what the engineers do. Our hires need to have a fundamental understanding of engineering, and then excellent problem-solving, writing, communication, and people skills." – Senior Industrial*
> - *"In my current career of pharmaceuticals, training is a must. The client of ours has an online training program (awareness and comprehensive) for procedures that are maintained electronically. Each group within the organization has a training coordinator." - Industrial*
> - *"A lot of what else I needed to learn was specific to the company I took a job with: the culture, specific process, software, etc. I feel my degree did as much as it could without training specific to my company." – Industrial*
> - *"Schools should emphasize teaching fundamentals. Many business, project-management, and economic topics are best learned on the job." – Industrial*

Education after employment begins. The practical response of industry is formal training programs for new employees, both in general and job-specific topics. 50% of those in industry feel that recent BS/MS graduates need more workplace preparation, and 79% said that their recent hires did require some type of additional workplace preparation. Most recently hired respondents (90%) stated that they needed some sort of additional workplace preparation when starting their current job.

Requirements for ABET accreditation now include that students will be prepared for lifelong learning. That post-graduation learning usually starts on the first day of work with company policies, including. Process safety is a common focus for initial training or reinforcement, and this training is a vital part of building a company's safety culture. However, some survey respondents said that was the only formal training they were provided.

> ***Mentors are vital, but expect to teach yourself, too.***
> - *"The transition from classroom to chemical plant required effort on my part to take the initiative to go around the plant and learn about all of the things I had not learned in the classroom. I frequently went to my boss and other coworkers to answer the many questions I had when I first started." – Junior industrial*
> - *"All my training was on-the-job training. No structure existed for new engineers when I was hired. One had to figure out how to do the job by learning from others." – Junior industrial*

When asked in the survey, "What types of additional workplace preparation, if any, did your new hires (past 3 years) need?", 64% of the senior industrial respondents cited professional mentoring, 40% cited self-instruction, 25% cited seminars, 14% cited additional coursework, and 21% asserted that no additional preparation was needed. By comparison, the junior respondents 67%, 64% (much more self-instruction), 27%, and 16%, with only 10% saying they needed no additional preparation. Academics had assumed that graduates would need job-specific preparation.

In response to this need, 82% of senior industrial respondents said their companies offered in-house, company-run training programs; 63% offered on-line training programs; and 51% assigned one or more professional mentors internally. Third-party-run training programs are common as well, 50% of companies offering them offsite and 38% onsite.

In addition, some respondents reported having development programs, including assigned mentors, technical (classroom) training, and job rotation. Formal training varies widely. An issue brought up by a senior industrial respondent was that initial training typically takes three years, which is too long because job attrition begins to take place.

(1.3) Summary of industrial perspective on undergraduate preparation for industrial careers.

Core Technical Fundamentals Are Required but Are Not Sufficient. The most important aspect of the undergraduate academic training for the industry bound engineer appears to be teaching of the fundamentals (thermodynamics, heat and mass balances, biochemistry, chemistry, math, etc.) of chemical engineering and these fundamentals are taught well. Both the more senior industry responders in the survey and the junior responders ranked these topics as highly important. More junior responders also included business issues and safety training. (The first is only covered in a limited sense in the academic environment; business and safety may be important because junior individuals often are initiated to engineering with safety issues). Additional focus on more advanced chemical engineering topics was considered the least important.

Technical Aspects of Engineering Need to Be Emphasized (Understand processes and equipment, and solve practical problems that happen with them). Engineers hired into industry are expected to know or learn how equipment and processes work and how to solve problems that occur while using the equipment or running the process. Fixing real-world problems usually requires critical, independent thinking, and applying the knowledge of fundamental chemical engineering to problems in a systematic manner, simplifying the complex problem to a number of smaller ones that are tractable. Often, a fundamental knowledge of the typical equipment is very helpful (common process equipment, valves, exchangers, pumps, etc.) and the basic elements of the control system and instrumentation. Thus, example problems where the solution requires a broader use of data about the equipment, its safety limitations, and how that may vary based on process performance would be instructive.

Learn Some Tools Directly Useful in Industry. Industry-bound engineers would benefit from more familiarity of common tools used in their potential new industrial positions. A simple understanding of P&ID drawings would be very helpful for any junior engineer. An undergraduate engineer should leave his/her undergraduate training with a reasonable depth of understanding of a company's calculation tool (Excel in particular). Some familiarity with other systems would be very helpful (specific control systems, computer simulators (AspenPlus, SINET, HTRI), AutoCAD knowledge, and tricks for programs like ASPEN and MATLAB.

Finally, as most engineers have to deal with safety issues early in their career, learning about with specific process safety training concepts is important area to add to the curriculum, including Environmental Health and Safety hazards and issues, HSE / OSHA / PSM issues (including fault-tree and risk analyses). This preparation is very helpful in quality control and company risk management also.

Communication and Critical-Thinking Skills Can and Must Be Incorporated into Seminars and Projects. The scope of jobs that a chemical engineer can undertake has changed dramatically over the years. Few undergraduates understand the breadth of utility of a chemical engineering education based on their academic work and are usually only introduced to the wide variation of career paths after many years in industry (process engineer, operations engineer, safety engineer, validation engineer, development engineer, operations engineer, quality engineer, etc.). A review of these options as part of the training could be very beneficial.

The soft skills quickly become essential for a rising engineer in industry, particularly effective communication (verbal & written) and teamwork among individuals with a wide variety of backgrounds and technical skills. Academic projects and courses in which teams of students with varied backgrounds would expose undergraduates to leadership positions, conflict resolution, and time-management skills, and as well as financial constraints imposed by time and budget.

Finally, using project courses to hone critical-thinking, time-management, and self-learning skills would prepare students better for an industry position. New graduates are often challenged in applying critical-thinking skills to workplace problems, and creative problem solving does not come naturally to most of them. They often do not know how to define a problem, ask hard questions, or critically evaluate work in the literature or by their colleagues. Such skills should be a focus of lab courses and projects.

Practical Experience outside the Classroom Is Extremely Valuable. There is no question that summer jobs and co-op experiences can be powerful forces for student insight. At the same time, the academic experience must provide ample lab and project experiences to connect with what is said and read about physical phenomena and the importance of communication skills.

(2) Preparation of M.S. students for industrial careers

Industrial participants in the workshop stated that M.S. and Ph.D. candidates are evaluated on a case-by-case basis, so the best question is whether the choice of doing an M.S. satisfies the individual's expected needs.

The M.S. degree in chemical engineering is seeing a modest resurgence. A current trend in ChE is awarding "professional" non-thesis master's degrees on-campus: 12-month degrees if coming in as a BSChE, an additional semester of courses if not. These degrees may also be earned through distance education or by a mix. Many universities are using these programs as a means of generating funds through tuition, as students are expected to provide their own support.

Several factors make the M.S. degree attractive to students as well. One reason is the chance to deepen understanding beyond the B.S. using additional coursework. This need is one of the reasons for pressures to limit professional licensing to people who have the M.S. (or equivalent) and above.

Also, the M.S.Ch.E. can a good way to re-brand and get a new skill set. For example, if it is a way to backfill what skills you have like a chemist who wants to be certified as a ChE and needs the foundational preparation, the M.S. may be very useful. If a company can get more competence for the price, it is happy with the M.S. graduate. One academic described having an M.S. program to help international students transition to the U.S. marketplace. A similar decision process occurs for the many B.S. Ch.E. graduates who decide to pursue an MBA. A person who is in industry and needs more background could get a master's degree to change the personal/professional equation.

Industry's receptiveness is important. During the energy crisis of the 1970s, M.S. graduates and even B.S. graduates could be hired directly into research and development. That is seldom the case now, so there began to be no strong reason for a BSChE doing it -- they would end up doing the same thing as a BSChE, albeit with more depth. This greater depth is an enhancement over the B.S. preparation, especially for the thesis master's. Many of the larger companies would rather hire a Ph.D., but small and medium companies can be more receptive. The degree can be a solid foundation to move up in management, as well.

Industrial participants in the workshop acknowledged key similarities and differences between the thesis and non-thesis master's. In both cases, there is the expectation that M.S.Ch.E. graduates are qualified as chemical engineers. Having a thesis project is a desirable attribute. Just like an internship, it is an effort that takes a lot of work and, more importantly, helps build critical soft skills. However, a thesis takes a lot of work and funding from the PI and the institution.

For a student's deciding to do a master's or making a choice between the thesis vs. non-thesis masters, it's a matter of personal return on investment, financially or otherwise. The burden is on the individual to determine if the degree is worth the price.

The degree of preparation in the non-thesis MS often reflects effort and structure of the given academic institution. Consider the MIT School of Chemical Engineering Practice (the "Practice School"). It is a non-thesis master's but involves coursework and a series of in-industry, intensive, one-month team projects. How does the professional masters program relate to that? In both cases, you gain maturation and skills.

For the thesis vs. non-thesis masters, it's ultimately a matter of ROI. If you want a masters, it might well be a way to backfill what skills you have. The individual will be compensated more for the masters – but they have to do their own calculation.

(3) Preparation of Ph.D. students for industrial careers

What makes a PhD a PhD is the ability to analyze the problem or opportunity and propose how to proceed, including in new areas. The initial attribute being sought in Ph.D. graduates is that they can address an important research problem creatively at the frontier of the discipline.

Both in the 2013 Annual Meeting plenary on "Chemical Engineering Expertise in Academe and as Sought by Industry" by Chen, Cruz, Krishna, and Poehlein and the survey/workshop for the present study, the breadth of industry expressed a perception that there are important gaps in the preparation of ChEs.

These gaps play out differently for Ph.D. students for industry than for B.S. students. The survey showed that in general, participants from industry believe that PhD programs address all subject areas better than BS/MS programs do. 41% of senior non-academic respondents believe that recently hired PhD graduates are prepared to meet the needs of the jobs for which they are hired.

Out of ~700 chemical engineering PhDs graduated per year in the US, about 85-90% go into industry. Clearly, the biggest customer for PhDs is industry. The desired characteristics are a record of initiative and accomplishment in the dissertation research and evidence of creativity and critical-thinking skills. For some jobs, the initial placement will be in the graduate's area of research, but for others, potential is the dominating factor. One company described their objectives, "We're not looking for corporate management; we're looking for technical leaders and future senior scientists." They acknowledged that the best of these new employees might well move to corporate management, but that evolves rather than being planned at the outset.

Technical expertise and technical sophistication are expected from PhDs.

"PhDs are typically narrowly focused projects, and one has to separate the preparation of the PhD course load (many programs don't even require a course load beyond MS) from the major area of study. I expect PhD candidates to be well prepared with a deep knowledge of their area of study, whether it is biotechnology, modeling and computational sciences, or something else." – Industrial

(3.1) Technical and soft-skills preparation

Technical preparation, soft skills, and practical experience have parallel importance for Ph.D. students. The technical preparation of students coming from non-ChE backgrounds is a separate challenge.

Certain technical skill sets are expected, although they often hard to separate from non-technical skills. Foremost are high technical skill levels and knowledge of fundamentals at advanced levels. In many cases, companies are looking for someone who is a chemical engineer or someone who has those foundations, although they reported that they make their assessments without relying on the discipline named in the degree. Those foundations are expected to require basic ChE course(s) if the student didn't have that background initially.

The doctoral research focus gives a natural foundation for the soft skills of critical thinking and communications. Depending on the type of individual research, though, there may be little opportunity for the team skills of group projects. Likewise, there are important differences relative to the workplace in the decision processes about research and the usual insulation from financial decision-making.

Researcher needs in ChE process sciences. With the shift of funding towards areas such as biotechnology and nanotechnology in past years, it has become more difficult for the industry to find professionals with research experience in process-science areas of chemical engineering, such as reaction engineering, separations, solids handling, and control. In many cases, researchers with the proper fundamentals can make the transition to such chemical engineering problems quite quickly, but this gap has led to some frustration by recruiters.

This reaction was perceived both in the survey's open answers (e.g., *"We struggle to find PhD ChEs with research interest and specialized knowledge in traditional chemical-engineering disciplines, including reaction engineering, separations, fluid mechanics, and solids handling"*) and in the discussion during the workshop. Notable examples were discussed of how a few major chemical companies are trying to address the gap by making considerable investments sponsoring research in areas more applied to their current needs.

A more definitive solution would require a stronger alignment with the funding agencies to attract and support more applications for research projects in the traditional fields. NSF's CBET Division has been moving toward greater support through initiatives on topics like Smart Manufacturing and process intensification.

Data analysis. Stronger fundamentals and application of statistics, data analysis, and modeling make up another critical element of the formation of chemical engineers. Entry-level professionals in the industry often are lacking in this area, and even new PhD hires are not sufficiently familiar with these approaches. The ability to collect, mine, and, most importantly, extract information from large data sets is essential for Chemical Engineers and should be a requirement for graduate students, regardless of their research field. For engineering purposes, big-data analytics and statistics are focused on getting all the data and then converting it into information for decisions and actions.

Multidisciplinary approaches. The importance of multidisciplinary approaches to addressing challenging problems, research topics, and global megatrends is a consensus in both industry and the academia. A professional that can operate across different sciences, areas of engineering, and research fields are of great interest to industry. For example, a chemical engineer might collaborate with material scientists and physicians on the development of biomaterials and surfaces for implants or drug delivery. Similarly, a reactive-flows experimentalist might collaborate with a CFD modeler from Mechanical Engineering and a computational quantum chemist.

Multidisciplinary/transdisciplinary experience is desirable. This behavior/competence should be fostered in the preparation of masters and PhDs by making available diverse coursework and supporting collaboration across research groups and departments in different fields.

Teamwork and leadership skills. The industry seeks not only the most brilliant researchers but also people capable of working and leading large, multifunctional teams. Though employers have the tools in place to develop these skills after a researcher joins industry, it is advantageous to seek opportunities to exercise teamwork and other soft skills during their studies. Among the survey responses, project management, collaboration tools, communication (especially the ability to present technical information to non-technical people) and basics of finance were highly recommended.

Intellectual-property management. The protection of proprietary information and understanding the options to protect a technology or secure the right to practice is of great importance for industrial research. Both students and faculty often lack proper training. This gap can be addressed by seminars, workshops, and training material with IP attorneys or the university's IP department.

Problem-solving skills. Problem-solving skills were highlighted as the most important competency sought by industry and one of the defining elements of what it means to be an engineer. The wide range of challenges emphasizes that there are common elements in applying critical thinking to develop advances, from developing a new product to controlling a challenging reaction to devising an improved supply-chain network for shipping a chemical product.

This skill set should include the ability to understand the nature of the problem that needs to be solved, to collect the appropriate data and ask the right questions, to analyze those data, to develop hypotheses and ways of proving or disproving them, and to propose and validate a solution that will ultimately address the challenge. Such elements are mostly covered by the proper application of the scientific method, but young professionals are not always prepared to apply it when the problem to be solved is too open or unclear. Industry recognizes that it takes time to master that skill set, and most large companies will have specific methodologies for problem solving as part of their training programs for new hires. Such methodologies and tools can also be made available as seminars or lectures in academia. They must be exercised through application in the students' own research or using case studies suggested by industry, with proper coaching and empowerment by their advisors.

Potential. For industry, potential is more important than specific research experience / topic area. The degree of emphasis on potential depends on the company: Its size, its immediate vs. long-term needs, and so on. Industry does have an interest in research-based approaches. They used to hire based on talent and potential, but didn't care about the engineering side. On the other hand, if you have two candidates and both offer the same potential and one of them has better research, then research gets hired. If one has better potential, that person gets hired over the research.

Summarized expectations. Participants in the workshop developed a summary list of what industry expects from new PhDs. It provides a useful basis for aligning faculty and student expectations with industry expectations.

- First and of central importance, a clear grasp of ethical expectations and of personal and process safety.
- Initiative (although how do you teach it?) while being flexible and balanced.
    - We end up with some people who are so tied in to their thesis and topic that they can't see the multiple aspects of the work.
- Competence in analyzing a problem or opportunity and proposing how to proceed.
    - Ability to translate a specific study into addressing a need.
- Ability to extend their skills to be able to assemble a project or business plan, recognizing that multidisciplinary skills and interactions are necessary.
    - Ability to sell their research ideas effectively through independent proposal or some other mechanism.
- Being savvy about financial impacts.
    - Be well oriented to financial management and accounting.
    - Timescales: Market scale or what time frame do you want to work on?
    - How do you connect your work to the value proposition and to the business model?
    - How well can you talk to customers or economic drivers?
- Ability to go into a new area and learn enough to pick up and run.
- Ability to innovate – people who can think and do work in new areas and then translate it into whatever the industry is looking for. Big-picture thinking requires understanding the marketplace, too.
- Ability to identify future issues – being forward-thinking.
- Ability and expectation to be a technical team leader or topic leader – "instant expert."
    - Need to develop the ability to mentor effectively.
    - Be used to working in teams and with diverse, multidisciplinary groups – happening because the activities are multidisciplinary, the problems more complex.
    - Some PhDs go onto the corporate management track, and some do quite well. The younger PhDs often end up going over to management after 5-10 years.
- Capability in IP issues.
    - How do you know what makes a patent?
    - Do you know how to identify patentable problems?
    - That includes basics like keeping a notebook correctly.
- Knowing when to stop – how do you deal with the technical hurdle rate? What's the ROI based on the money you have to bring forward?
    - We do have people who get tied into a project psychologically, and then we must help them understand when to stop. "When do you stop?" hasn't been taught in grad school.
    - 90% of what you do won't work, so figure out where it might be useful and have a fallback plan. This should be part of our routine preparation and training of students.

What makes them scientists and PhDs is seeking and finding an intellectually interesting story, then telling it well by oral and written means. What makes them <u>engineering</u> scientists and PhDs is their understanding and speaking the shared language of engineering, grasping implications of the science for application to real-world products or processes, and drawing from different disciplines for different problems toward the desired outcomes; that is, "Directed innovation."

(3.2) Practical experience and exposure to industry

The survey and workshop brought out the importance of practical experience for new Ph.D. hires, while recognizing that dissertation research often provides many such opportunities. Practical experience was considered very important or extremely important by 61% of the respondents for PhD roles. That level is lower than for B.S.Ch.E. graduates, but it is still quite high.

In addition, students should be provided additional opportunities to learn about and get exposure to the industry. It is a way of better preparing them for industrial roles, if that is their career choice. On the other hand, if they decide to stay in academia, it also will give them a more solid understanding of industrial needs, processes, and jargon, which will make them more effective researchers and faculty.

This exposure can be implemented with a strong offering of industrial seminars, mentoring programs with alumni working in industry, participation in research programs with industry or internships with industry, ideally on the scope of their research project in order not to reduce focus or delay their thesis.

Major mechanisms for industrial experience for graduate students are summer internships or targeted short-term visits that are part of a research project financed by industry. From anecdotal evidence, it appears that students doing theoretical or computational research work are more likely to do summer internships, especially if companies are affiliated with a consortium or else are directly financing a research project. In contrast, students who do experimental work are less likely to participate in industrial internships but may be more likely to work for periods of time in national laboratories.

Internship is not as important at the PhD level as at the BS level, as jobs and dissertation research can be very different depending on type and focus. Practical training in industrial setting can be valuable.

> ***Internships for PhDs can be useful complements.***
> *"At the PhD level you're looking for different skills than you are when you're looking for an undergraduate. An internship may not give you those same skills. Also PhDs have more maturity and experiences in general than undergrads, which makes internships less interesting." – Industrial*

Another important factor in graduate education is that the research is often connected to other industries than the traditional chemical industries. For example, in biomedical engineering research, hospitals may be the place of "industrial experience."

(3.3) Improving graduate studies for non-ChEs

Nontraditional students can bring important skills into the lab and class. Coursework and approach differences between BS and graduate degrees add complications.

The number of grad students in chemical engineering who don't have ChE backgrounds depends a lot on the particular school. One response would be to recommend that there shouldn't be any ("Don't let the structure drive the need"). However, industry is going out to hire someone who has a skill set rather than a set number of courses.

Students coming with a bachelor or masters degree in other sciences or engineering areas bring a diversity of skill sets and innovation into chemical engineering research. Many notable examples were discussed about successful chemical-engineering professionals with undergrad education in chemistry, biochemistry, electrical engineering, or civil engineering.

What do such students need to be recognized as chemical engineers? Workshop participants recommended that they should have UG transport, thermo, and kinetics in preparation for the ChE grad courses. The contention was that, "Without separations and reaction engineering, they are not well prepared for industry jobs in any sector. Typically the company will try to milk the thesis experience for a year or two, but after that, all bets are off. "

Some universities address the issue by establishing mandatory coursework for non-chemical engineers in pursuit of an advanced chemical engineering degree. Another approach is using PhD qualifying exams or admission exams to assess prior or completed preparation in critical tools and competencies, such as separations, reaction engineering, and data analysis.

Workshop participants discussed how standardized criteria and qualification processes on critical fundamentals might be helpful. To standardize criteria across different schools and to increase awareness by industry of tools in place to ensure solid chemical-engineering fundamentals, three key competency clusters were suggested:

- Ability to study, model, and control chemical and biochemical processes;
- Data analysis; and
- Problem solving / critical thinking / communications.

Industry participants again asserted that they evaluate each candidate individually, so uniform standards of preparation or qualification are not so important to them for hiring purposes. On the other hand, a separate opinion was that common expectations of how ChE PhDs are prepared would result in higher standards and better preparation nationally and internationally.

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(4) Preparation of faculty for the core curriculum

To educate undergraduates or graduate students in chemical-engineering fundamentals, faculty members must be well prepared themselves. Teaching a new class usually requires self-preparation for any faculty member. At the least, they need to refresh their orientation to the details of the subject and possibly add new content or pedagogical tools like electronic media or class management software. If they do not have prior experience with the topic, more preparation is necessary.

A set of workshop attendees described their assessment of the present trends as follows:

- Most ChE faculty members hired in the last 30+ years in the US have **no prior industrial experience**, while most UG classes require practical input for a well-rounded education of students, a majority of whom join industry upon graduation.
- Except for a few lectures given as part of their TA assignments or when a faculty member (typically their PhD thesis advisor) is away for a few days, most newly hired ChE faculty members have **no prior experience in teaching**.
- With the shift towards more science-oriented research, particularly biotechnology and nanotechnology, many newly hired ChE faculty members had **no exposure to core ChE topics in their ChE graduate education and research.**
- In light of available research funding opportunities, there is an increasing trend towards **hiring of faculty members with non-ChE educational background,** particularly chemists and materials scientists.
- One academic participant stated that, consequently, half the faculty in his department "cannot teach the core classes."

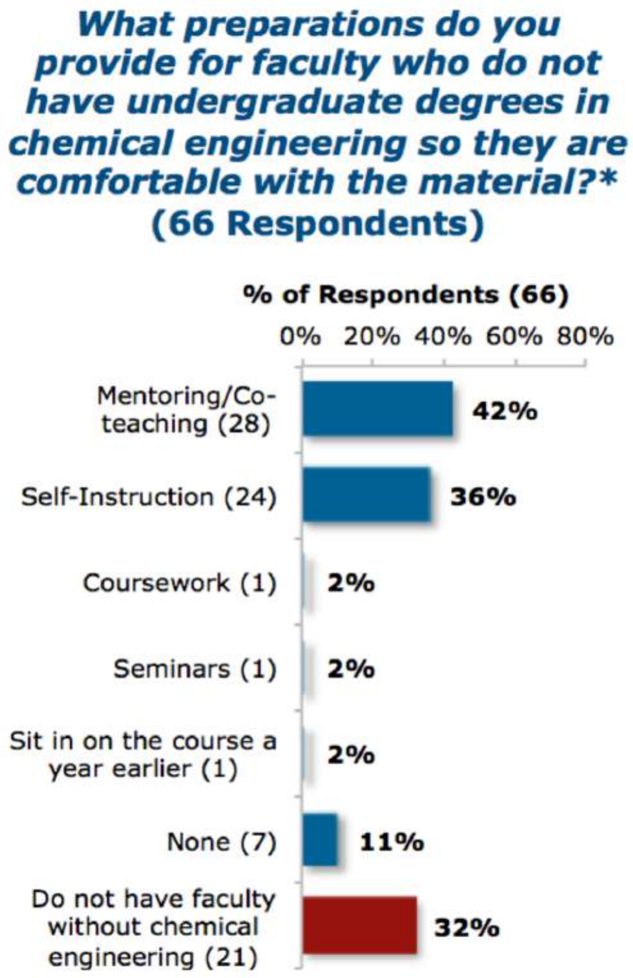
Workshop participants insisted that all faculty should be able to teach the core undergraduate courses if they have a good textbook and the understood expectation that they are expected to do so. The faculty member's attitude is central.

The profession and its stakeholders all want to encourage faculty to be knowledgeable, effective educators. Matching faculty expertise and faculty interest plainly helps, as people who are intellectually interested in the topic will learn the area. At the same time, the expectation of their being engaged and effective must be clear to all busy faculty members – not just junior faculty. Some schools emphasize a rotation of teaching assignments after three or four years, both to drive freshness in teaching for the faculty and for students. For the faculty member, such rotation provides broader insights into the connections across the curriculum and deeper insights into the particular subject,

(4.1) Preparing non-ChEs for effective core UG classes

New faculty members who do not have undergraduate degrees in chemical engineering usually are expected to learn how to teach core undergraduate courses, although not always. Workshop participants noted that from the outset, it is important to set the expectation that ChE is going to become one of their professional homes at the very least. Teaching the undergraduate courses can be very helpful in these faculty members learning fundamentals of the profession. For the students' sake, these faculty members should get help in learning the corresponding content, context, and phenomena.

From the 66 academic respondents to the survey, 28 reported use of mentoring or co-teaching; 24 relied on the new faculty members' self-instruction; 11 said they didn't provide any preparation; and 21 said it was not an issue because they didn't have any faculty who didn't have a BSChE.



(4.2) Preparing all faculty for effective core UG classes

Not only new faculty without ChE undergraduate degrees and/or industry experience, but also new faculty in general and teaching a new course can benefit from preparation aids. This assistance can take many forms:

Co-teaching. In this approach, the first time a new faculty member teaches, he/she is paired with a more senior faculty member, and both co-teach the course. Team teaching can really help someone who really doesn't have the prior background to teach a subject in depth. It also provides access to different teaching models.

To set up the co-teaching, identifying the right people to team with can be challenging, as is allocation of time.

The new teacher learns about the teaching method (write on board, prepare overhead transparencies, PowerPoint slides, and so on), extent of detail provided in lectures, type and frequency of examples in lectures, interaction with students (both during lecture and in office hours), number of homework problems/exams and their difficulty, expectations of TAs, and grading.

Understudy teaching is a practice that has been followed by the University of Minnesota for nearly 50 years. One faculty member gives the lectures, while several (at all levels of seniority) conduct recitations and also attend the lectures to see what the students are learning at a given time. No faculty member is assigned the teaching role for a course unless he/she has previously served in the supporting role.

A variation at North Carolina State University is that the normal first assignment for new faculty is ChE 205, the Material and Energy Balance course. The teaching team is led and directed by Prof. Lisa Bullard, Director of Undergraduate Studies and co-author of the textbook used.[13] Each faculty member is assigned a separate 50- to 75-person section, and exams are held in concert. However, even for non-BSChE-prepared faculty, the faculty preparation is more about active-learning methods and other teaching / assessment styles than intellectual content.

Sitting as a student in lectures given by an experienced teacher. This approach can be very helpful if the material is completely new. The course is usually one that the new faculty member is expected to teach in the future. They sit in the lectures given by an experienced teacher to learn all the points noted above. It can also be a very valuable part of co-teaching.

ASEE Summer School for ChE faculty. Participation is recommended for all new faculty, particularly those with a non-ChE background. This is a career development event for new ChE faculty members, held once every five years.[14] The next summer school will be held July 29-August 4, 2017 at North Carolina State University in Raleigh, NC.

One of the reasons the Summer School works is because attendees have begun teaching or know that they will be assigned to teach thermodynamics or some other course, and they are eager / desperate for material. Summer school instructors know proving materials on content and assessment is very effective. Rather than hearing a presentation about engineering science or industrial application, the recommended approach is to provide

[13] R. M. Felder, R. W. Rousseau, L. G. Bullard, *Elementary Principles of Chemical Processes, 4th Edition*, New York: Wiley (2015).
[14] http://www.engr.uky.edu/~aseeched/index2.html

modules and examples. Demonstrating best practices for incorporating these aspects makes it easier for attendees to incorporate and use the materials.

Use readily available educational materials. Faculty members are made aware of the Computer Aids for Chemical Engineering (CACHE) website (www.cache.org), where they can access a variety of educational materials. Over the years, CACHE has helped to create a number of case studies, e.g. related to process design, as well as educational resources in topics such as reaction engineering, thermodynamics, process control, statistics, conventional and renewable energy, and others.

AIChE's Safety and Chemical Engineering Education (SAChE) program (http://www.sache.org/) also provides very useful teaching materials and programs to bring elements of process safety into core UG courses.

Use readily available software for courses. Adoption of MATLAB early in the curriculum (e.g., in the introductory material and energy balance course) and throughout the curriculum can prepare students for its use in later courses. As a useful computational and data analysis/visualization tool for many UG core courses, it also provides faculty members with a uniform computational tool for the full curriculum.

The use of Aspen Plus software for equipment design, operation, and optimization is common in most courses related to separation processes and process design.

Add guest lectures from industry experts. The regular lectures can be augmented productively by a certain number of guest lectures by experts from industry. They bring practical examples linked to the course subject, which usually motivates students to learn specific topics based on their importance in practice. Similarly, including an industrial advisor for a course's instructor can help relate topics to current issues within industry.

Set up an industrial course advisor. Company recruiters or other contacts can help set up industrial ChEs who are willing to act as points of contact for case-study backgrounds and for commentary on course content.

(4.3) Helping faculty implement professional preparation

Having some industrial or consulting experience results in faculty members who are better able to give perspectives on application of the core ChE topics.

While in the past it was common for faculty to spend few years in industry before joining the university to teach and to do research, the more common path these days for young faculty is to do a postdoc with a well-known scientist. A major motivation for young faculty aside from gaining experience in a different field is to help them bolster their number of their publications and citations. There are obviously benefits to the chemical engineering profession with these multidisciplinary interactions.

However, this state of affairs increasingly causes faculty to be more and more inexperienced with industry concerns. A clear manifestation of that is the teaching of the design course. Most young faculty feel either incapable of teaching such a course or else they are simply not interested as this course is regarded as being "too practical." Due to this situation, a trend in the recent past has been for many universities to hire adjuncts (mostly retired people from industry) to teach the design course. While there is certainly value in bringing experienced industry people into the classroom, it is also clear that not having regular faculty involvement in these courses means that conceptual or theoretical concepts are not covered, and, moreover, connections with the rest of the courses in the curriculum are not established. The lack of industrial experience among faculty also means that in core courses in chemical engineering, few practical engineering aspects are highlighted.

Several critical areas emerged that faculty members need to focus on in preparing students for industrial careers, based on the survey, workshop, and reflections from the workshop. In the survey results, 94% of academics believed that students are adequately prepared, with only 6% recognized any gap in preparation. On the senior industrial (non-academic) side, 83% agreed that recently hired PhD graduates met the needs of the positions that they were hired for, but in contrast, 81% judged that BS/MS graduates need more workplace preparation.

Overall, the discussions and survey pointed to good training in fundamental chemical engineering skills but lacked in the applied nature (e.g., what to do and how to create value from application of concepts). This observation drove the discussion and identification of gaps, including:

- Communication skills (written & verbal)
- Process-safety management and general safety training (e.g., chemical hazards)
- Business and financial skills (return on investment, NPV)
- Experience in the field – especially practical skills in plant operations
- Leadership and supervisory skills
- Six-Sigma techniques and skills
- Intellectual property management
- Teamwork concepts and dynamics
- Realistic troubleshooting and problem-solving skills

Discussion of potential solutions and what can industry do to aid faculty in preparing students better led to suggestions:

- Participate in the classroom with special lectures focused on applied topics and real-life challenges in the field of chemical engineering.
- Enable co-op and internship programs at both the BS and PhD levels.
- Sponsor more industrial R&D collaboration projects at universities where industrial members are participating on teams with academic scientists in joint R&D efforts.
- Employ more academics as consultants in industrial environments.
- Open up more industrial R&D sites for academic sabbaticals - and encourage their use.
- Enable industrial scientists to be adjunct faculty members concurrent with their industrial careers.
- Participate in curriculum development with faculty

members, inserting practical application problem-solving into the course syllabus and better examples in textbooks.

Potential solutions that faculty members can address directly would include:

- Include more interdepartmental programs and curriculum elements into base chemical-engineering coursework:
  - Student involvement with technical writing and more presentations that engage expert communicators from other departments.
  - Team building with engagement of social science experts.
  - Business case analyses – Techno-economics and "Business 101" fundamentals.
- Open up classrooms: Invite industrial scientists.
- Ensure industrial experience is a component in some fraction of the current faculty.

In general, the gaps identified were more general in nature beyond sharing an element of chemical engineering. Having such fundamental chemical engineering gaps was considered likely to become an issue in the future. There was a clear recognition as the research landscape is evolving, not taking action will cause more pressure on those faculty members who are best prepared to teach fundamental ChE concepts effectively.

The presumed solution is that faculty should be encouraged and expected to engage in the core ChE curriculum regardless of their present and future new research directions.

New graduates and their educators must balance great breadth with depth in insight: "Engineering intuition."

"The biggest thing is the fundamental concepts. If you are designing a new unit, you will likely be a part of a team with at least one experienced engineer. While the final-stage particulars will need to be established with more complicated models, the fundamental exercises (i.e. McCabe-Thiele analysis) can tell you a lot of information up front to guide the design. If you are in production like myself, there are a lot of resources available to deal with the particulars of your operation. Yet here again, the fundamentals are the guide. One of the big trends we look at in our morning meeting is Reflux Ratio!" – Junior industrial

"Alongside future engineers, other students, less numerous, have their turn to become teachers; they therefore must they go to the foundations; a thorough and rigorous knowledge of first principles is their foremost need. But this is not a reason for not cultivating intuition in them, for they would misrepresent science if they never regarded that side, and furthermore, they might develop capabilities in their students that they do not possess themselves…

It is by logic we demonstrate; it is by intuition that we invent. Knowing how to criticize is good; knowing how to create is better."

-Henri Poincaré, Définitions mathématiques dans l'éducation, 1904

"Engineering intuition is a learned thing, not an inborn one."

-Michael Modell, Discussion of 10.40 graduate-thermodynamics homework

(5) Roles of industry in aiding effective preparation

In the sections above, several steps were identified by which industry can engage with academia for better preparation of chemical-engineering undergraduates, M.S. students, Ph.D. students, and faculty. It is in the best interests of educators and of industry to do so.

The vast majority of graduates are employed by industry in a wide range of areas, including more than 85% of the chemical engineering PhDs. Process and energy industries are still the dominant hiring sectors; however, we have seen increasing penetration in other industrial sectors such as pharmaceuticals, biotechnology, and electronics. It is imperative that companies help provide opportunities for students, as well as faculty members who teach chemical engineering, to gain industry exposure with relevant engineering practices and examples.

Today's students are tomorrow's employees. Industry is the ultimate beneficiary of better-prepared chemical engineering graduates. Better-prepared new hires translate to shorter learning curves, higher productivity, and greater contributions to companies' bottom lines.

At the undergraduate level, companies could contribute in many additional ways to provide relevant industry exposures to students and faculties:

- Providing more internship opportunities to undergraduate students is beneficial.
- Providing real industry examples to faculty who teach design classes will make the class exercises more relevant.
- Sponsoring industrial guest-speaker series by identifying senior industry experts who are interested in giving seminars and pairing these experts with local universities.
- Sponsoring individual undergraduate design projects and multi-group competitions would expose students to known challenges and even development. It will be valuable for companies at all sizes to continue to participate and sponsor more of these types of activities.

At the graduate level, it is in general more difficult to promote industrial experience due to thesis research requirement and funding situation. To promote internships to graduate students, companies will need to be more involved in identifying and establishing joint development opportunities with universities. Many companies participate in technology-specific industry consortiums to sponsor research in the universities. Funding projects through these consortiums provide dialogues between industry needs and academic research. The approach has been adapted and proven effective, especially for shorter-term MS level projects. Industry could also consider partnering with universities to secure funding from government for major step-change technology development. Carbon capture and sequestration is one such successful example, and the approach could be applied to other areas.

Given the fact that chemical engineering is an engineering discipline that is largely linked with the process and energy industry, and increasingly with other industrial sectors such as pharma, biotechnology and electronics, it is clear that chemical engineering students should be exposed to industry practice during their education. Likewise, faculty who teach chemical engineering should be knowledgeable about engineering practice in industry. Industry must be involved in providing this experience.

At the graduate level, it is in general more difficult to promote industrial experience, unless companies fund more research projects at universities. These could promote internships as part of the research could in fact take place in the companies.

At the level of faculty, it would appear that there is an urgent need for industry to become more pro-active and offer post-doc positions in R&D to young faculty. In that way faculty could become more engaged with industry, and establish long-term relationships with them. An important challenge for industry, aside from the financial one, is how to allow for the young faculty to publish during these industrial postdocs. Here again, industry might need some special incentives, perhaps from the government, complemented perhaps by ABET requiring a minimum percentage of faculty having some industrial experience. On the other hand, one could also argue that if industry does not step in and become more proactive, it might jeopardize their future prospects for hiring competent chemical engineers who have a good appreciation of industry and the engineering profession.

From the above, it is clear that greater cooperation and communication is needed between academia and industry to promote industrial experience among students and faculty. But ultimately no significant changes will take place unless industry takes the lead in these initiatives for promoting industrial experience.

Industrial participants in the workshop asserted that industry ultimately needs to become more involved in the educational process, recognizing and accepting that it is the beneficiary of better-prepared chemical engineering graduates. Taking active roles and investing necessary resources and opportunities for students and faculties is necessary for its own success.

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(6) Roles of professional societies in aiding effective preparation

Professional organizations such as AIChE,[15] ACS,[16] APS,[17] CCR,[18] MRS,[19] ASEE,[20] and CACHE[21] play important roles in shaping the education of students:

- A central focus of AIChE's Education Division is education of chemical engineering undergraduates, and its other divisions and forums are deeply involved as showcase for outstanding student research. AIChE Academy [22] is the wide-ranging source of online distance-learning materials, targeted seminars, in-company classroom courses, and video-recorded conference materials with a particular focus on aiding the workplace transition for new graduates.
- Scientific organizations like the American Chemical Society, the American Physical Society, the Materials Research Society and others also provide venues for research presentations and publication.
- The Chemical Engineering Division of the American Society for Engineering Education (ASEE) publishes *Chemical Engineering Education*, a journal that includes profiles of educators and departments, teaching advice, and content for new-course and -module development and implementation. It also organizes the ASEE Summer School for Chemical Engineering Faculty, where chemical-engineering education leaders present and provide carry-away materials for course content and pedagogical approaches, focusing on new faculty.
- CACHE (Computing Aids for Chemical Engineering) began in 1969 and brought FLOWTRAN, the precursor to ASPEN, to chemical engineering computer classrooms. Since then, it has developed useful codes like POLYMATH and conference and online teaching modules in areas including computer-aided process design, process operations, process control, molecular modeling, and systems biology, balancing engineering science and educational content.

Conferences. Holding conferences and workshops for educators is an important role for all these organizations. In larger conferences with parallel sessions, educational sessions compete for attention with research sessions.

However, plenary sessions focused on education preparation draw widespread interest, as evidenced by the 2013 session that gave rise to this study, as well as by the 2014 AIChE Institute Lecture by Ed Cussler on "The Future of the Lecture." [23] CACHE research-focused conferences often include one session on educational approaches about the technical topic of the meeting, and attendees frequently noted that they like engaging with this broader aspect of their research impact.

By emphasizing particular research topics, professional organizations also steer the directions of the curriculum and

[15] http://www.aiche.org
[16] http://www.acs.org
[17] http://www.aps.org
[18] https://www.ccrhq.org
[19] http://www.mrs.org
[20] http://www.engr.uky.edu/~aseeched/
[21] http://www.cache.org
[22] http://www.aiche.org/academy

[23] E.L. Cussler, "The Future of the Lecture," 2014 AIChE Annual Meeting, Atlanta GA, Nov 16-21, 2014; http://www.aiche.org/chenected/2014/11/ed-cussler-66th-aiche-institute-award-winner-on-future-lecture

of new faculty. The impact of ACS on curriculum is relatively diffuse because most of its divisions focus on chemical principles; Industrial and Engineering Chemistry is a major exception. For AIChE, there are presently two major meetings per year:

- The Spring Meeting, usually held in a Gulf Coast location, is a practice-oriented meeting with a strong participation by the oil and petrochemical industries. It features sessions organized by divisions plus a collection of topical meetings, some quite well established. For example, the 2016 AIChE Spring Meeting includes the 12th Global Congress on Process Safety, the 28th Ethylene Producers' Conference, the 19th Topical Conference on Refinery Processing, the 16th Topical Conference on Gas Utilization, the 4th International Conference on Upstream Engineering and Flow Assurance, and a long-running Distillation Symposium. There is only modest student and faculty participation. One reason is the timing in the middle to end of the busy spring semester, but another is because in many of the focus areas, little graduate research is conducted at present.
- The Annual Meeting is a larger, research-focused conference, heavily attended by faculty, students, and industry, where industry participants are principally in research and development areas.
- Other regular AIChE conferences during the year are on Metabolic Engineering, Synthetic Biology, and the Symposium on Safety in Ammonia Plants and Related Facilities (the 60th in 2015). There is also AIChE participation in smaller conferences and workshop and in international multi-organization conferences. The latter meetings often include education topics.

The AIChE's programmatic division into practice-oriented and research-oriented national meetings is an evolved format that is effective from a technical standpoint. However, its Spring Meeting might be used much more effectively for student and faculty preparation than at present.

Continuing education. AIChE and CACHE place strong emphasis on continuing education for chemical engineers. CACHE's main continuing-education activity is its conferences. Its undergraduate-oriented teaching modules are also useful for industrial ChEs who are seeking added preparation through self-study.

"AIChE Academy"[21] is set up to provide an extensive set of education and training resources to chemical engineers and the companies they work for. In general, it focuses on lessons pertinent to practice and industry-specific needs rather than duplicating undergraduate material.

There is a searchable list of material at basic, intermediate, and advanced levels:

- eLearning courses;
- Classroom-format courses for the public or in-company;
- Frequent live instructional or informative webinars that are then archived.

Content areas include ChE practice, process safety, chemicals & materials, biological engineering, sustainability and the environment, professional development, and energy. Some of the online material is pre-bundled by content area.

Conference presentations are also available from AIChE meetings and its entities: the Center for Chemical Process Safety (CCPS), the Society for Biological Engineering (SBE), the Institute for Sustainability (IfS), and the International Society for Water Solutions (ISWS).

Member connections. One valuable aspect of any professional organization is connecting its members in useful ways. Post-graduation mentoring could become a formal activity of AIChE's local sections. AIChE's Council of Fellows (the elected, highest grade of membership) already seeks to connect its members with students. AIChE could also help set up industrial advisors for faculty handling specific courses. [Departmental Industrial Advisory Boards are another useful source of contacts for this purpose.]

(7) Roles of government agencies in aiding effective preparation

Federal government agencies affect chemical engineering education directly by sponsoring development of educational approaches and tools. Some of the tools are specific to technical topics within chemical engineering, such as the Etomica software of Kofke and co-workers.[24]

Agencies also affect education indirectly by their choice of emphases for topics of research funding. This pressure is more subtle and often diffuse, but it has profound effects on the direction and content of education for PhDs and undergraduates alike. Current and new faculty must secure funds if they are to lead graduate-level and post-doctoral researchers, and they must pursue areas where they can obtain funding.

Influence of research-funding directions. Research cannot be conducted without researchers, and availability of funding for paying researchers and their expenses drives the direction of research.

> ***Research funding shapes the profession.***
> *"Funding agencies such as NSF must take a large part of the responsibility for newer faculty members working in areas more remote from the ChE industrial core as their funding emphasis becomes more and more fundamental and science-based. Universities are not blameless in that they want to hire new faculty in fundable areas so the new faculty can bring in more research funds to cement their tenure. It's a vicious circle." – Survey participant*

The principal costs of academic research are student/post-doc support and indirect research costs, although research equipment, supplies, necessary travel, and related operating can be quite large expenses.

In the US, the norm is that Ph.D. students in chemical engineering are fully financially supported by a stipend for living expenses, varying from about $20,000 to as high as

[24] http://www.etomica.org

$42,000; tuition and fees; and health insurance. These amounts ordinarily come from research grants:

- Stipend levels are influenced more by competition for the best students than by local cost of living. In the experience of graduate program directors, students instead seem to decide based more on departmental ranking or geographical location, but factors like the stipend, departmental culture, and suggestions by their undergraduate faculty have important secondary influences. Some institutions provide supplemental fellowships or allow students to receive both departmental stipends and external fellowships at the same time. The stipends are direct costs and so are charged overhead at rates of 35% to 85%.
- The cost of tuition and fees varies greatly among institutions. It is not subject to indirect-cost charges.
- Health insurance is usually paid directly but may come out of the stipend.
- Indirect research costs vary widely around a level of 50% of direct costs. Such costs may be described as "maintenance of sophisticated, high-tech labs for cutting-edge research; utilities such as light and heat; telecommunications; hazardous waste disposal; and the infrastructure necessary to comply with various federal, state, and local rules and regulations."[25]
- Funding for research equipment is necessary, whether for individual laboratories or shared facilities.

Federal agencies have become the predominant source of research funding for academia since World War II. Engineering faculty sought to become more science-focused in their research, encouraged by industry, which hoped to use this science and results from their corporate research laboratories to develop new processes and products. As Federal funding of engineering science increased at universities and Federal national laboratories, industry decreased its sponsorship of academic research. [Industry has reduced its corporate research laboratories over the last 50 years, leaving fewer corporate scientists to extract useful knowledge and applications from the university research.]

Major sponsors of chemical engineering research at the Federal level include the National Science Foundation (NSF divisions notably including CBET and DMR), Department of Energy (DOE through its operating divisions and Office of Science), National Institutes of Health (NIH), National Institute of Standards and technology (NIST), and the various organizations within the Department of Defense (DoD: ARO, ONR, AFOSR, and DARPA). They have different responsibilities and different methods of operation. At NSF, research-funding budget allocations are strongly influenced by proposal pressure (number of submissions in a given area), although NSF staff members can highlight topics through sponsoring workshops and studies. Funding for temporary topical initiatives then can be sought based on expressed interest by possible principal investigators, intellectual merit, and broader impacts, and potential for being transformative. At DOE and DoD, program officers have more autonomy to choose research directions, although their funding is also affected from above by larger trends.

Engineering researchers' need for funding far outweighs funding availability. Proposal success rates of a few percent are common when PIs respond to unrestricted or specific funding opportunities. When increased funding does appear, there is a "rush to the side of the boat" that can drive additional funding allocations and additional people on that side of the boat. There are limits to the extent that this unstable movement can occur, but within strong limits to total funding, the effect is also to reduce other types of research.

Specific impacts on ChE directions. Government funding has responded to and shaped the most prominent new research trends in chemical engineering during the last 40 years. The biggest impact on chemical engineering research and education has been the shift from emphasis on research on process sciences to product sciences. Funding availability drives the availability and appeal of dissertation projects, which drives candidate expertise and faculty hiring.

- **Computing**, originally for simulation and process measurement and control, now also for molecular modeling and information analysis;
- **Materials science**, originally focused on development of new materials and then nanotechnology; and
- **Biomolecular science and engineering**, growing from classical fermentation and separations to biomedical engineering, biomaterials, drug delivery, tissue engineering, systems biology, and metabolic engineering.

The shorthand perception was "BioNanoInfo." Growing environmental awareness in the 1960s and 1970s also gave rise to anti-pollution and later sustainability research. Similarly, the rising cost of energy drove large government investments in research on energy from coal in the 1970s and later in solar energy, fuel cells, and batteries.

Below, the 2013 survey by John Chen shows the effect through examining the time evolution of focus using professorial rank: Emeritus, Professor, Associate Professor, and Assistant Professor. This axis is not linear, but it show clearly the shifts of faculty expertise from process science as "UO" (thermodynamics, transport phenomena, separations, particle technology, and systems) to the nanotechnology and biological areas.

Faculty are able to and should provide excellent education in thermodynamics or material and energy balances or design or dynamics and control if their research expertise is in bioscience, as only one example. Achieving such excellence can be more challenging, due to lack of prior experience with a course topic or its practical application. Most importantly, it requires a commitment by the individual to provide that excellence and by the department and university and profession to expect it, to support it, and to reward it.

Generating graduates with research expertise in the process sciences is influenced by the perceived appeal of the topic. Part of the appeal is having exciting problems in terms

[25] Association of American Universities and the Association of Public and Land-grant Universities, "Frequently Asked Questions (FAQs) about the Indirect Costs of Federally Sponsored Research," October 2013, <https://www.aau.edu/WorkArea/DownloadAsset.aspx?id=14693>.

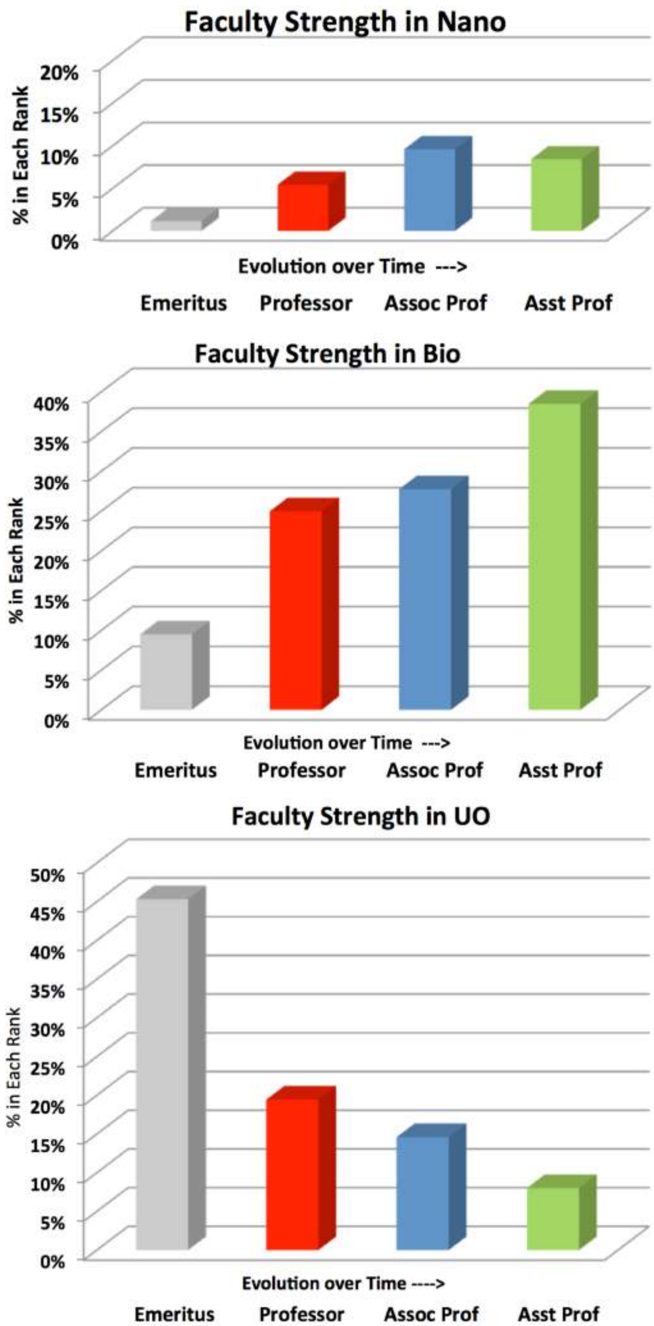

Figure. Time-wise evolutions of changed distribution of research emphases in academic chemical engineering, as indicated by expertise at different seniority of faculty ranks.

of intellectual development and societal / technological impact. Acting on those possibilities and even their appeal are aspects that are inevitably shaped by whether industry and government promote the importance of these areas through research funding.

Roles of government: Summary. Government agencies continually work to aid development of the workforce and of the technologies that commerce and society need. Increased support for research in the process sciences is one area where more can be done.

The Federal government is currently sponsoring a National Academy of Engineering study through a Committee on Understanding the Engineering-Education Workforce Continuum.[26] Its upcoming report will be based in part on a November 29-20, 2014, workshop on “Pathways for Engineering Talent,” whose content is available online.[27]

Agencies presently use a variety of mechanisms to develop needed research, researchers, education, and educators:

- There was broad support for government support to support developing educational methods and materials.
- Research initiatives are generated by many agencies, relying on re-allocation of budget or new funds provided by Congress. Topics are generated in response to topical opportunities, growing societal or technological needs, and intellectual developments.
- “Young Investigator” awards are made by several agencies, including NSF, DOE, and ONR. The earlier NSF Presidential Young Investigator awards were effective for developing engineering educators in part because they required matching funds from industry to achieve the maximum level of funding; that was dropped for the current CAREER award program because it was quite difficult to obtain such matching in the sciences. The CAREER awards require a thoughtful educational plan for developing that aspect of a faculty career.
- Industry/NSF collaborative funding endeavors include the SBIR awards, which can engage faculty and students, and GOALI awards, which fund collaborations in which academics spend time working in industry and/or industrial people spend time working in academic groups.
- NSF’s Research Coordination Networks support interactions among academics and industry on leading-edge research topics. Workshop participants suggested there could likewise be “education coordination networks” of a parallel nature.
- Some workshop participants supported the idea that government could aid development of a set of area examinations that could be used to gauge whether students need to take remedial ChE courses, analogous to the ACS examinations for Inorganic / Organic / Physical / etc. Chemistry. Others questioned the value of such standardization and, if it should be appropriate, whether it was the place of government or professional societies to lead.

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26 Committee on Understanding the Engineering-Education Workforce Continuum, <https://www.nae.edu/Projects/Continuum.aspx>.

27 NAE Workshop on Pathways for Engineering Talent, <https://www.nae.edu/Projects/Continuum/nov19webcast/123918.aspx>

Summary of recommended actions

Recommendations for preparation of undergraduates.

- Maintain a **technical focus on the fundamentals**, developing students' grasp of concepts and of the diverse application contexts.
  - **Increase the range of technical and non-technical topics covered, carefully including more selective in-depth study**.
  - Apply new emphasis to **process safety, process dynamics, applied process control,** and **applied statistics** through new teaching materials and effective integration into the curriculum.
  - Integrate **process and product development and design**, including sustainability as a design principle.
  - **Re-emphasize and actively develop soft skills:** communications skills, especially writing; critical-thinking skills; leadership and team-function skills; open-ended task analysis and problem solving; and time management. Make it clear that core technical fundamentals are required but are not sufficient.
- **Connect the fundamentals to practice** through in-course examples and practical professional experience.
  - **Aid placement and emphasize value of co-ops and summer jobs** as being increasingly important in hiring. However, requiring co-ops for everyone isn't necessary or practical.
  - Incorporate **problem-solving methodologies and case studies for practice** into the curriculum.
  - Incorporate **one-time guest lecturers from industry**.
  - Arrange **industry course consultants** for instructors.
  - **Provide basic IP training to undergraduate and graduate students**, both on recordkeeping and on identifying potential intellectual property.
  - Make clear to students that **having work experience is more important than international experience for new graduates** (language skills, immersive education or work), although in-depth international experience is considered valuable.
  - Make clear to students that **they will be expected to continue learning after graduation**, formally or not.

Recommendations for preparation of M.S. students.

- Recognize that industry expects M.S.Ch.E. graduates to be qualified as chemical engineers. If they come from non-ChE BS degrees, they will be expected to have the fundamentals.
- Provide "professional" non-thesis master's degrees recognizing that they can be valuable to a student as continuing education or re-credentialing, but the choice of doing so depends on the individual's expected needs.

Recommendations for preparation of Ph.D. students.

- Clarify to PhD students and to faculty what industry expects of them (note that workshop participants prepared a helpful summary list that is more extensive):
  - PhDs usually transition smoothly into industrial positions when their doctoral research and first job are closely related, but their **career development requires breadth**.
  - **Industry's most desired characteristics are a record of initiative and accomplishment in the dissertation research and evidence of creativity and critical-thinking skills.** For some jobs, the initial placement will be in the graduate's area of research, but for others, potential is the dominating factor.
  - **Industry expects a minimum set of core competencies for** graduate students to be considered **M.S. or PhDs in Chemical Engineering**:
    - Ability to study, model, control chemical processes (including biochemical);
    - Data analysis skills;
    - Problem solving skills applied to chemical and biochemical engineering cases.
- **For students from non-ChE disciplines** entering ChE PhD studies, provide effective exposure to and strengthening in the **breadth of core chemical-engineering topics**.
- **Encourage PhDs to seek pre-graduation professional development** whether they expect to enter industry or interact with industry as academics. Make sure they understand the differences of approach and goals between the expectations of academic research and industrial R&D.
- Prepare PhDs better to **adapt to industrial work environments and communication styles**.
- Consider whether common expectations or testing of how ChE PhDs are prepared would result in higher standards and better preparation nationally and internationally

Recommendations for preparation of faculty

- Make it clear to all faculty members, especially new hires, that they are **expected to lead courses in the core ChE fundamentals** and to understand how the topics fit into the curriculum and the diverse profession.
- Aid all faculty members to **build and maintain a sound, sufficiently deep perspective on the core curriculum**:
    - o **Use the ABET process** to aid faculty-wide understanding of the content of courses across the curriculum.
    - o **Recognize that faculty attitude is most crucial** for framing a topic's technological context effectively -- being open and inquisitive about the specific content and its context, the broader curriculum's topics, their connectedness, and their applications.
- **Provide support for faculty teaching subjects new to them** by:
    - o Sharing previous course materials;
    - o Providing instruction on how to teach effectively with new material and with new teaching technologies;
    - o Coordinating teaching and use of software like MATLAB and ASPEN through the curriculum;
    - o Providing mentoring through consultation with previous instructors, team teaching, or previewing by sitting in the course before assuming the instructor role;
    - o Arranging industry-based course consultants;
    - o Arranging participation in the ASEE Summer School for Chemical Engineering Faculty;
    - o Acknowledging the necessity of self-instruction.
- **Help faculty with professional preparation of students**.
    - o **Encourage industrial consulting and industry visits, collaborations, and sabbaticals**, which results in faculty members who are better able to give perspectives on application of the core ChE topics. Experience in national laboratories can provide similarly relevant experience.
    - o Within courses, bring in one or two **guest lecturers from industry** to aid the faculty in the face of decreasing levels of industrial and consulting experience among faculty.
    - o **Consider using ABET to monitor industrial experience among departmental faculties and assess impact**. It would be challenging to do in an enforceable and non-prescriptive manner.

Recommendations for industry.

- **Provide expanded co-op and summer-job opportunities** to undergraduate students.
- **Provide industry examples to faculty who teach design classes** to make class exercises more relevant.
- **Sponsor industrial guest-speaker series** by identifying senior industry experts who are interested in giving seminars and pairing these experts with local universities.
- **Sponsor individual undergraduate design projects and multi-group competitions**.
- **Identify research collaborations between industry and academia driven by industrial needs.** Such collaborations would be financially supported such that academia can afford to participate (research support, education funding support, equipment support).
- **Support industrial sabbaticals and internships for academics**, sponsored by industry with targeted problems to be solved in an industrial environment. A side benefit is to "reintroduce" the industrial influence in department cultures, which enables integration of soft skills.

Recommendations for professional societies.

- **Develop conference programming that bridges researchers and industrial practitioners.**
- **Organize collaborations involving industrial technical entities to develop educational materials, texts, and problems.** Work with AIChE Academy to identity experts in industry who can advise academics and develop appropriate online and other training for new faculty (and others interested) in the industrial perspective on subjects. Dissemination is key according to participants, and it should be incorporated into a broader effort to enhance quality of instruction. Sustainability must also be considered. AIChE and/or ASEE are natural homes, but these activities must have a financial support mechanism to sustain the effort beyond startup funding.
- Help build **a** curriculum for **undergraduate use of problem-solving methodologies and case studies for practice**.
- Help young, smaller companies to **discover the value of sponsoring co-ops and internships**.
- **Provide professional mentoring for new graduates.**

Recommendations for government agencies.

- Sponsor development of **educational approaches and tools**.
- In research funding, **rebalance the process engineering and product engineering emphases** to provide key process science (thermodynamics, kinetics, transport phenomena, systems engineering) and to prepare a long-term balance of graduate expertise.
- Consider supporting **"education coordination networks"** for interactions among academics and industry on leading-edge curriculum development.

Attachment: Statistical summary of survey (slides).

amgRESEARCH

Academic Alignment Study

AIChE
The Global Home of Chemical Engineers

AIChE-NSF Chemical Engineering Industrial-Academic Alignment Study

Final Report

February 2014

amg RESEARCH
Providing Strategic Guidance
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❖ 1101 Parkway View Drive ❖ Pittsburgh, PA 15205 ❖ (412) 787-4166

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I. EXECUTIVE SUMMARY

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Executive Summary

- **AMG Research contracted with the American Institute of Chemical Engineers (AIChE) to conduct a study to better understand the alignment between academic outcomes and industry expectations.**
- **Out of the 13,088 contacts provided by AIChE, a total of 570 people completed the online survey - a 4.4% response rate.**
- **The 570 online surveys consisted of the following:**
  - Academic (66)
  - Senior Non-Academic (Bachelors before 2001) (267)
  - Junior Non-Academic (Bachelors after 2001) (237)
- **Based on the 570 surveys, the following observations have been made:**
  - Less than half of faculty members have non-academic chemical engineering experience. Only about a fourth of institutions screen applicants based on this.
  - The chemical engineering field covers a wide variety of work sectors. About half of those working in industry work as Process Engineers or in Research & Development.
  - Almost all institutions either survey alumni or use industrial advisory boards to obtain ABET-process feedback.
  - Energy is the area where respondents expect the most potential for growth in career opportunities for chemical engineering graduates in the near future.

Executive Summary (Cont.)

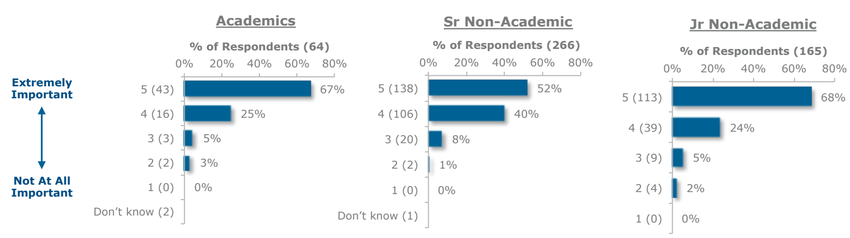
- Observations (Cont.):
  - While the academic segment placed slightly higher importance on the subject areas investigated compared to the non-academic segment, both almost completely agree on the order of importance.

Areas	Academic Average Importance	Sr Non-Academic Average Importance	Difference
Core chemical engineering sciences	4.78	4.48	-0.30
Engineering and process knowledge	4.65	4.39	-0.26
Math and chemical, physical, and biological sciences	4.35	4.27	-0.08
Co-ops, internships, and/or faculty-supervised research	4.31	3.72	-0.59
Business, leadership, and project management	4.02	3.96	-0.06
Advanced chemical engineering	3.72	3.23	-0.49

  - A recent shift in research interests can be seen among faculty. This has not affected what is being taught thus far, but is predicted to have an impact in the future.

Executive Summary (Cont.)

- Observations (Cont.):
  - PhD graduates are viewed as being more prepared for the positions they are hired for compared to BS/MS graduates.
  - Most new hires need some type of additional workplace preparation or training when starting their jobs. This is more true for BS/MS grads than PhD grads.
  - Companies are more likely to hire individuals who have practical experience on their resume.
  - Practical experience is viewed as being extremely or very important to respondents in all segments interviewed. This is particularly true for BS/MS graduates.



  - **However**, very few (12%) recent graduates were required to complete practical experience as part of their degree requirements.

II. OBJECTIVES/ METHODOLOGY

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Objectives

Study Objectives

Overall:

- Obtain opinions on how prepared undergraduates and PhD graduates are for the jobs they are hired for.
- Assess if graduates need more workplace preparation, and in what areas.
- Assess a number of different subject areas in terms of career importance, present level of academic preparedness, and the need for more academic preparation.
- Identify areas of growing career opportunities for chemical engineering graduates.
- Assess the need for practical and/or intern experience for chemical engineering undergraduate students, graduate students and faculty.

Industry

- Assess the importance of recent hires possessing the skills that directly match their position requirements.
- Identify any technical training programs offered to newly graduated hires.

Objectives (Cont.)

Study Objectives (Cont.)

Academic

- Assess the importance of recent hires possessing the skills directly matched to the position.
- Identify additional coursework or other preparation required for non-chemical engineers entering chemical engineering graduate programs.
- Identify preparation provided to faculty who do not have chemical engineering degrees for teaching undergraduate courses.
- Identify what non-academic experience is useful for faculty members.
- Determine if the research interest of faculty limit their interest or ability to teach courses across the curriculum.
- Determine if respondents feel the shift has had an impact on what is being taught to chemical engineers.
- Obtain opinions regarding ABET-process feedback about students preparation upon graduation.

Recent Hires

- Identify areas where recent graduates feel coursework left them unprepared for their current position.
- Identify what type of additional training was needed for their current positions.

Methodology

Pre-Project Planning

- A kickoff meeting was held via conference call on October 23, 2014.
- A draft questionnaire was provided to AIChE on December 4, 2014.
- The questionnaire was approved on December 23, 2014.
- A link was provided for AIChE to test on December 30, 2014.
- The online version of the survey was approved on January 12, 2015.
- Pilot interviews were conducted January 13 thru January 15, 2015.

Database Management

- A database of academic professionals, established professionals, and early career professionals was provided by AIChE.
- The database included approximately 13,088 email addresses.

Data Collection

- A total of 570 surveys were completed online.
- All surveys were completed between January 13 and February 9, 2015.
- Respondents needed to either work in academia or industry to participate.
- Responses were restricted to 100 industry respondents who do not have hiring or management job functions.

Report Preparation

- Data from the surveys was assimilated and prepared for analysis.
- Appropriate charts, tables, and graphs were developed to illustrate the study results.
- A final report was provided to AIChE on February 27, 2015.

III. STUDY RESULTS

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Respondent Profile

Respondents' status determined the line of questions they were asked in the survey. Almost all respondents have a degree in Chemical Engineering or Chemical and Biomolecular Engineering.

570 Respondents Representing a Cross-Section of:

Status

- Work at a university (66) 12%
- Industry, B.S. before 2001 (267) 47%
- Work in industry after 2001 (237) 42%

Level of Education

- Bachelors (260)
  46% • Masters (119)
  21% • Doctorate (191)

  34%

Degree Field*

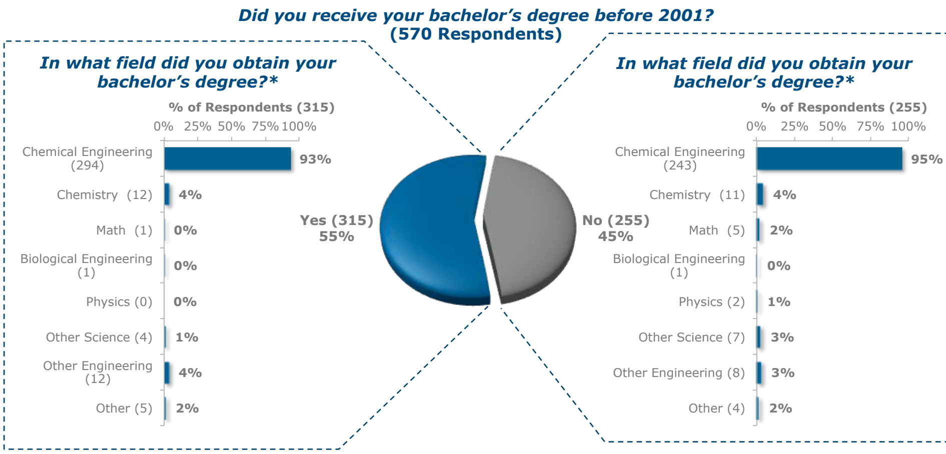
- Chemical Engineering or Chemical and Biomolecular Engineering (537) 94%
- Chemistry (23) 4%
- Other Engineering (20) 4%
- Other Science (11) 2%
- Math (6) 1%
- Biological Engineering or Biomolecular Engineering (2) 0%
- Physics (2) 0%
- Other (9) 2%

- Work at a university (66) 12%
- Industry, bach. before 2001 (267) 47%
- Industry, bach. after 2001 (237) 42%

*Multiple responses accepted.
( ) = Number of respondents.

Bachelor's Degree Field

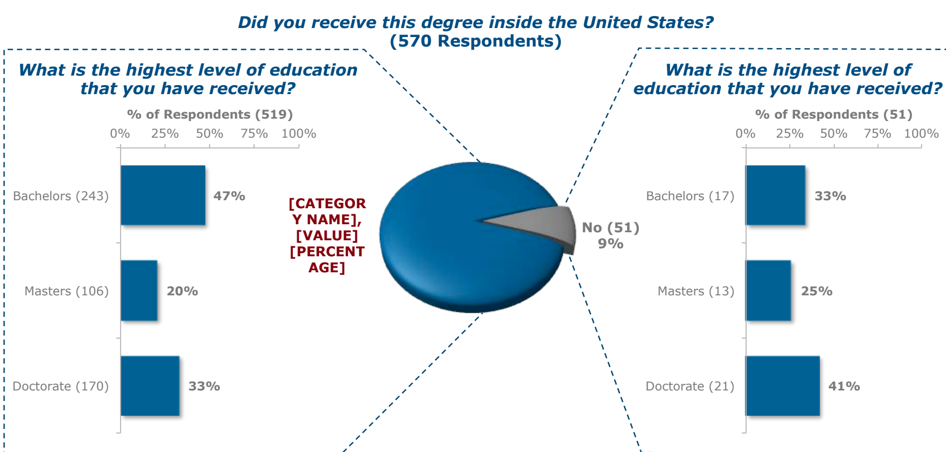
A good split of new and seasoned professionals was obtained. The types of degrees obtained has not changed over the years.



( ) = Number of respondents or times mentioned. *Multiple responses were accepted.

Education Level Achieved

A large majority of respondents received their degrees within the United States.

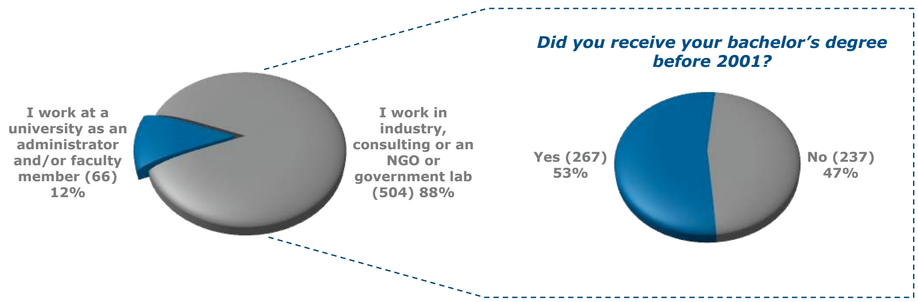


( ) = Number of respondents.

Employment Status

The number of respondents in each category is a direct reflection of the database that was provided to AMG Research.

Which of the following best describes your status?
(570 Respondents)



( ) = Number of respondents.

ACADEMICS

(66 Respondents)

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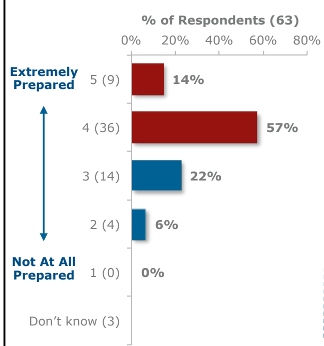
Undergraduate Preparations

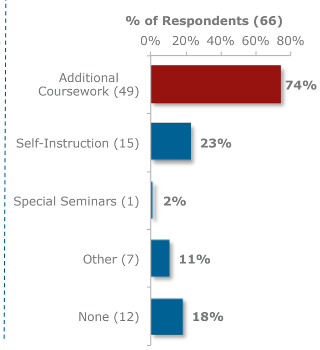
Academics

Respondents feel that undergrads are fairly well prepared for the positions for which they are hired. Additional course work is most likely necessary for a non-chemical engineer who is entering a graduate program. A third of schools do not have faculty who do not have a background in chemical engineering.

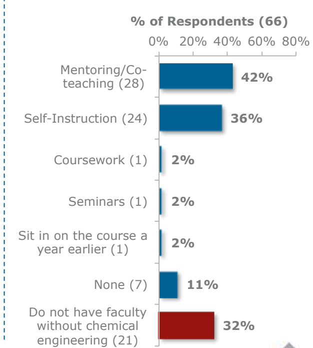
How prepared do you believe today's chemical engineering undergraduates are to meet the needs of the positions for which they are hired?
(66 Respondents)



What preparations do you require for non-chemical engineers entering your graduate program?*
(66 Respondents)



What preparations do you provide for faculty who do not have undergraduate degrees in chemical engineering so they are comfortable with the material?*
(66 Respondents)



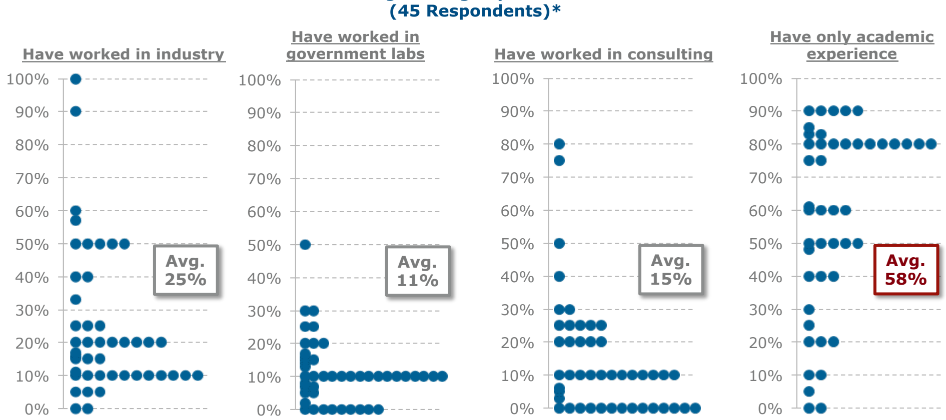
( ) = Number of respondents. *Multiple responses accepted.

Non-Academic Chemical Engineering Experience

Academics

Over half of faculty members do not have any non-academic experience. Experience working in industry is most common.

Approximately what percent of your faculty members have the following non-academic chemical engineering experience?
(45 Respondents)*



*Question asked only to respondents that work at a university with faculty that has non-academic experience.

Most Useful Experience

Academics

Industry experience is viewed as the most useful out-of-classroom experience for faculty members.

What non-academic chemical engineering experience would be/is most useful for your faculty members?
(45 Respondents)*

- **Industry experience (18)**
- Consulting (4)
- Project management (3)
- Advisory board experience (2)
- Design experience (2)
- Internships (2)
- Lab experience (2)
- Out of class experiences (2)
- Analytical training (1)
- International experience (1)
- Process engineering (1)
- Product development (1)
- Technical experience (1)
- None (1)
- Don't know (2)

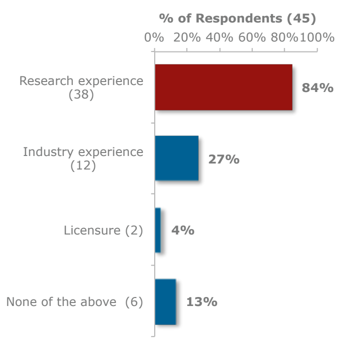
*Question asked only to respondents that work at a university with faculty that has non-academic experience.
( ) = Number of respondents.

Screening Applicants

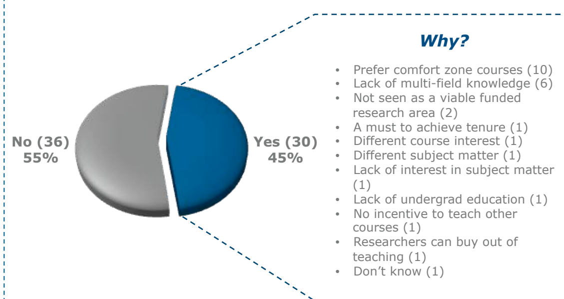
Academics

Research experience plays a huge role in being hired for a faculty position. Almost half of respondents believe research interests limit faculty's ability to teach across the curriculum.

Do you screen applicants for faculty positions based on any of the following? *
(45 Respondents)*



Do you believe the research interests of faculty in your department limit their interest or ability to teach courses across the curriculum?
(66 Respondents)



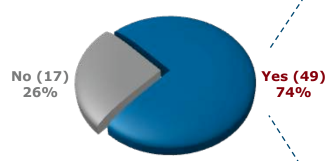
*Question asked only to respondents that work at a university with faculty that has non-academic experience.
( ) = Number of respondents. **Multiple responses accepted.

Institution Shift

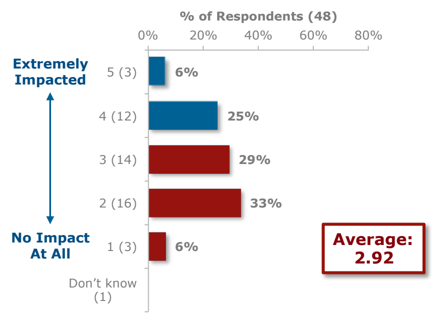
Academics

Three-fourths of those in academics agree that there has been a shift in research interests recently. Those who acknowledge the shift do not feel it has had a huge impact thus far.

Some observers suggest there has been a shift in the research interests of faculty recently. Have you seen a shift at your institution?
(66 Respondents)



How strong an impact do you feel that the recent shift in the research interests of faculty has impacted what is being taught to undergraduate chemical engineering students?



Average: 2.92

( ) = Number of respondents.

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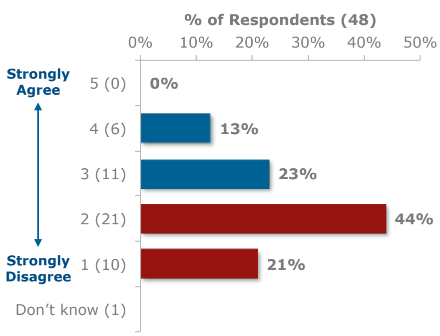
Institution Shift Opinions

Academics

Even though there has not been much impact yet, many feel there are going to be changes coming in the future.

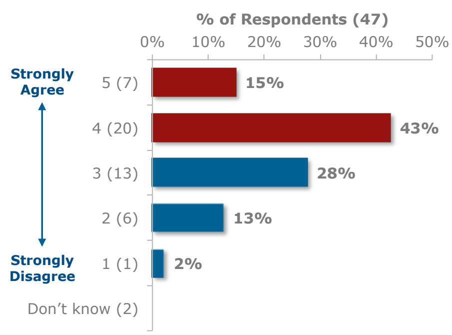
How strongly do you agree with the following statements?
Please use a 5 point scale where 5 = Strongly Agree and 1 = Strongly Disagree.
(49 Respondents)*

The shift in faculty interests is restricted to the short term.



Bottom Two Box: 65%

The shift in faculty interests is indicative of more drastic future changes.



Top Two Box: 58%

*Questions asked only to respondents who acknowledge a shift in research interests.
( ) = Number of respondents.

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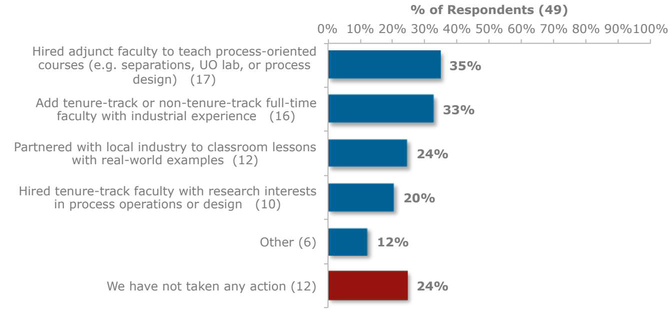
Actions Taken

Academics

Most (76%) institutions have taken action to accommodate the shift. Hiring adjunct faculty and full time faculty are the most common steps that have been taken.

Has your institution taken any of the following actions in light of this shift in the past ten years?*
(49 Respondents)**



Other responses include: Add non-tenure-track full-time faculty with research interests in engineering education (1), Hired adjunct faculty to teach courses related to materials, nuclear chemistry, and brewing (1), Hired adjuncts for other courses (1), My university initiated cluster hiring in sustainability, energy, and bioengineering (1), New faculty with specific research areas, with not much thought how they fit into teaching (1), and Seeking role (1).

*Actions were shortened to fit in the chart. Please refer to the questionnaire to see full action.

**Questions asked only to respondents who acknowledge a shift in research interests.

( ) = Number of respondents. Multiple responses accepted.

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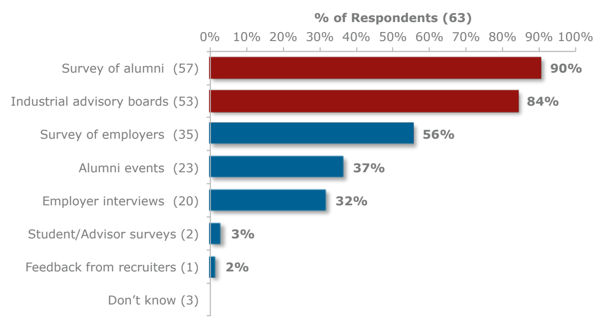
Actions Taken

Academics

Almost all institutions either survey alumni or use industrial advisory boards to obtain ABET-process feedback.

How do you obtain ABET-process feedback from stakeholders about how prepared students are at graduation?
(66 Respondents)



( ) = Number of respondents. Multiple responses accepted.

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Subject Area Importance

Academics

All subject areas have some degree of importance – no respondents rated any of them a "1" or not at all important. All subject areas investigated can be classified as extremely, very or somewhat important.

Please rate how important the following subject areas are in terms of career importance. Please use a 5 point scale where 5 = Extremely Important and 1 = Not at All Important.
(66 Respondents)

	Areas*	Importance Ratings 5	4	3	2	1	Average Importance
Extremely Important	Core chemical engineering sciences	80%	18%	2%	-	-	4.78
	Engineering and process knowledge	71%	23%	6%	-	-	4.65
Very Important	Math and chemical, physical, and biological sciences	52%	33%	14%	2%	-	4.35
	Co-ops, internships, and/or faculty-supervised research	51%	34%	11%	5%	-	4.31
	Business, leadership, and project management	26%	53%	18%	3%	-	4.02
Somewhat Important	Advanced chemical engineering	15%	48%	31%	6%	-	3.72

*Subject areas were shortened to fit in the chart. Please refer to the questionnaire to see full text.
( ) = Number of respondents.

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Academic Preparation Opinions

Academics

Less than 50% of respondents feel that many of the current subject areas covered in Chemical Engineering programs prepare students for employment. It is obvious that those in academics feel that some subjects are covered better depending on the level of degree that is being obtained.

How strongly do you agree that present academic preparation for ________ programs addresses the following subject areas relative to employment need? Please use a 5 point scale where 5 = Strongly Agree and 1 = Strongly Disagree.
(66 Respondents)

Areas	BS/MS Top Two Box	PhD Top Two box
Fundamentals of thermodynamics, fluid mechanics, heat and mass transfer	83%	84%
Chemical sciences, including general, organic, physical, and biochemistry	77%	62%
Mathematics, calculus, linear algebra, differential equations	64%	72%
Separation science and processes	58%	38%
Analysis and modeling, process simulation and optimization	51%	48%
Material science, nanotechnology and polymers	40%	57%
Process control theory and implementation	38%	24%
Biotechnology and/or biomedical engineering	37%	47%
Process and product safety	35%	27%
Data science and application: Design of experiments, statistics, analytics	26%	44%
Computational science and engineering	21%	38%
Business skills, leadership training, management, and economics	15%	12%
Innovation and entrepreneurial skills	8%	20%

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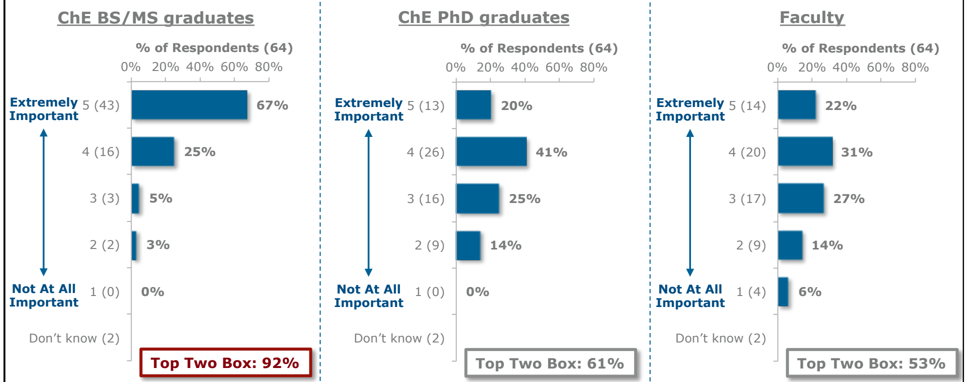
Practical Experience Importance

Academics

Practical experience is viewed as being most important for bachelors/masters students.

How important is practical experience (e.g., internships, co-ops, prior technical jobs) for chemical engineering BS/MS graduates, PhD graduates, and faculty? Please use a 5 point scale where 5 = Extremely Important and 1 = Not At All Important.

(66 Respondents)



( ) = Number of respondents.

Reasons for Practical Experience Importance

Academics

Some respondents do not feel practical experience is necessary because graduates will get on the job training.

Why do you feel practical experience is not important for BS/MS graduates, PhD graduates, and faculty?*

ChE BS/MS graduates (2)

- *Companies will train entry-level engineers and teach them everything else they need to know…*
- *Practical experience from observation seems to be limited to learning the operational culture of each company. Students never return with improved thinking, lab skills, or knowledge. Research internships should be limited to students that will pursue R&D careers, and should be determined through individual interviews and discussion…*

ChE PhD graduates (9)

- *Important for BS/MS. Not so much for PhD who will be trained by their employers…*
- *They'll get once they start work…*
- *They are already adequately prepared for on-the-job education.*
- *Most of the research at the PhD level is supported by NSF, NIH and DOE. Although there are programs that involve industrial partnerships and experience, it is not necessary for all students…Practical experience is important to some, but those will likely work on a project with this aspect.*
- *People who pursued a PhD should focus on R&D careers. Internships may be more useful for these, as long as they occur in R&D oriented environments…*
- *PhD graduates may be hired based on specific expertise rather than on industrial or other practical experience. Practical experience is a bonus, not a requirement in many cases.*
- *Purpose of PhD is to generate new knowledge while training for fundamental research. Industrial experience can impose a paradigm on the student's approach…*

Faculty (13)

- *For faculty it is not important…They can learn on the job…*
- *Given the country-wide reduction in course hours for a BS degree, the academic focus appears to be on the core science and engineering skills for BS graduates…*
- *It is less important for faculty and PhD graduates than for BS/MS graduates.*
- *It is useful for faculty, but should not be mandatory*
- *…The one area that may be improved by industrial experience would be to expose the instructors charged with process safety education to many short mini-internships…*
- *Modern ChE research is increasingly less industrially focused and more fundamental, oftentimes overlapping with chemistry and physics departments…*
- *Most faculty have not held industry jobs prior to faculty jobs…Since many are only interested in their research area for teaching, they have no desire to teach or have skills in the process design area.*
- *It's not the fundamental underpinnings of what they do.*
- *Research productivity and creativity are most important.*

*Question asked only to respondents who rated practical experience importance a "2" or "1".
( ) = Number of respondents.

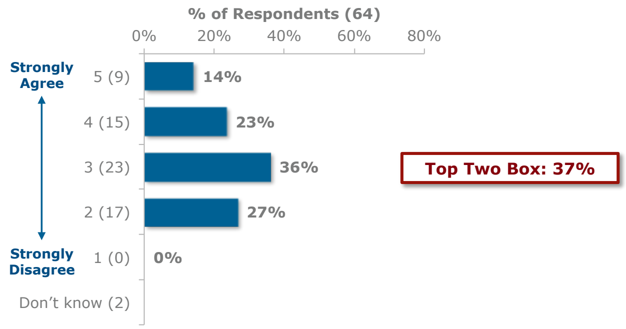
Academic Preparedness Opinions

Academics

There is not a huge push for more workplace preparation for BS/MS students; only about a third of respondents feel this is necessary.

How strongly do you agree with the following statements?
Please use a 5 point scale where 5 = Strongly Agree and 1 = Strongly Disagree.
(66 Respondents)

The BS students graduating from your institution need more workplace preparation.



( ) = Number of respondents.

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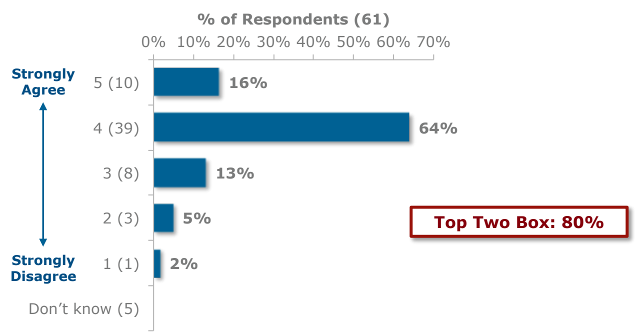
Academic Preparedness Opinions

Academics

A large majority of respondents feel that PhD graduates are prepared for the positions they are hired for.

How strongly do you agree with the following statements?
Please use a 5 point scale where 5 = Strongly Agree and 1 = Strongly Disagree.
(66 Respondents)

Your institution's PhD graduates are prepared to meet the needs of the positions they are hired for.



( ) = Number of respondents.

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SENIOR NON-ACADEMIC (Bachelor's before 2001)

(267 Respondents)

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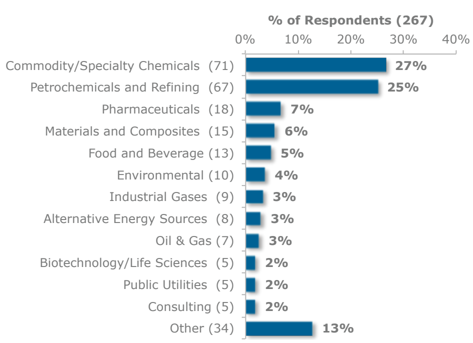
Sectors

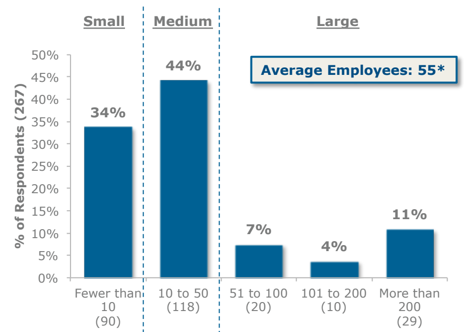
Those in industry cover a wide variety of sectors. Most work for small or medium sized companies.

Sr Non-Academic

Which of the following best describes the sector you work in?
(267 Respondents)



Approximately how many employees make up your department's engineering staff?
(267 Respondents)



Others include: Equipment (4), Multiple (4), Energy (3), Agribusiness (2), Consumer Products (2), Engineering (2), Government (2), Medical Device (2), Semiconductors (2), Biomaterials (1), Electronics (1), Flooring (1), Insurance (1), Investments (1), Materials Characterization (1), Metals (1), Nuclear waste management (1), Polysilicon (1), Research (1), and Simulation Software (1).

*Average does not include mentions of 1,000 (1), 1,200 (1), 1,500 (1), 1,800 (1), 2,000 (2), 2,300 (1), and 5,000 (1).

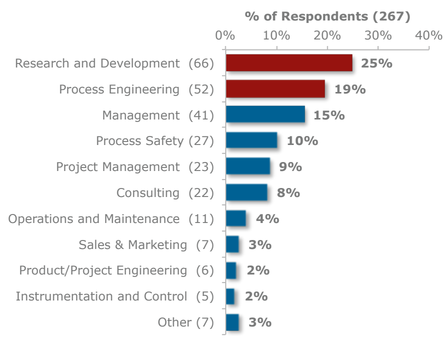
( ) = Number of respondents.

Job Function

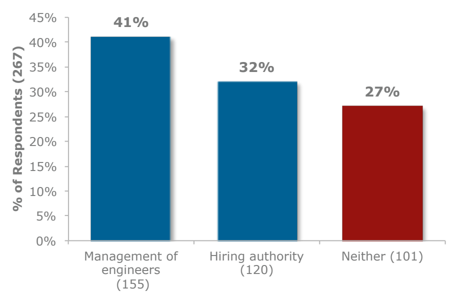
Sr Non-Academic

Research and Development and Process Engineers make up almost half of the industry people interviewed. The number of respondents who neither manage or hire engineers was limited to 100 responses.

Which of the following best describes your job title/function?
(267 Respondents)



Do your job functions include either of the following?
(267 Respondents)



Others include: Economist (1), Systems Engineer/IT (1), Multiple (1), Patents/Intellectual Property (1), Proprietor (1), Quality Assurance (1), and Technical Specialist (1).

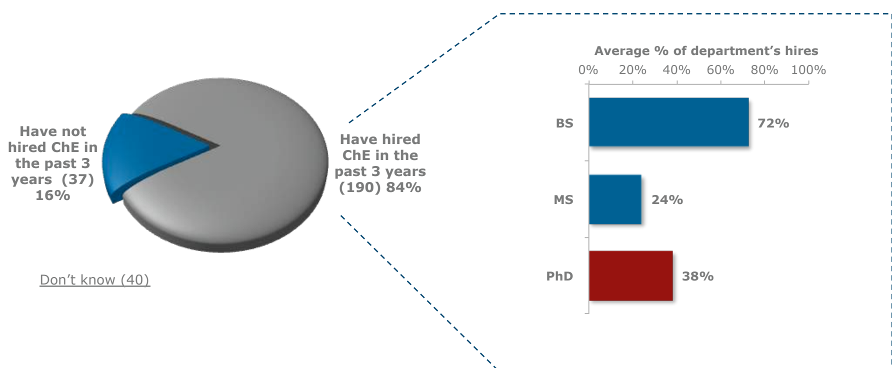
( ) = Number of respondents.

Department Hire Degrees

Sr Non-Academic

Over a third of those recently hired in industry have a doctorate degree.

Approximately, what percent of the following degree levels make up your department's hires of chemical engineers in the past 3 years?
(267 Respondents)



( ) = Number of respondents.

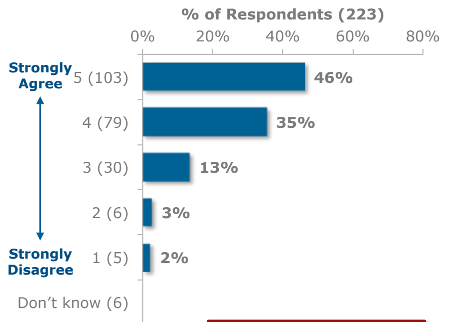
Academic Preparedness Opinions

Sr Non-Academic

Having practical experience gives candidates an edge when applying for a job in Chemical Engineering.

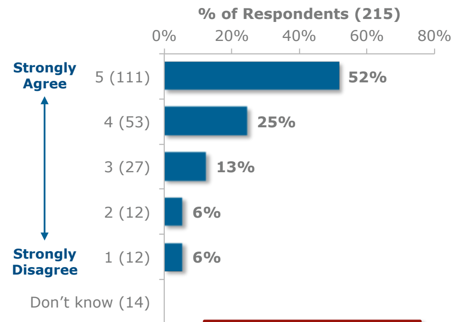
How strongly do you agree with the following statements?
Please use a 5 point scale where 5 = Strongly Agree and 1 = Strongly Disagree.
(229 Respondents)*

We are more likely to hire chemical engineers who have completed internships, co-ops, or other technical jobs.



Top Two Box: 81%

We are more likely to hire chemical engineers who have completed internships, co-ops, or other technical jobs inside our company.



Top Two Box: 77%

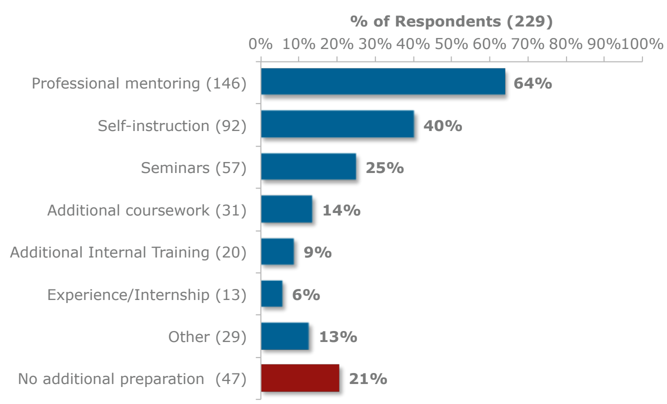
*Question asked only to non-academic respondents who have hired chemical engineers in the past three years.
( ) = Number of respondents. Multiple responses accepted.

Additional Preparation Needed

Sr Non-Academic

About 80% of new hires needed some type of additional workplace preparation. Professional mentoring and self-instruction are the two most common types.

What types of additional workplace preparation, if any, did your new hires (past 3 years) need?
(229 Respondents)*



*Question asked only to non-academic respondents who have hired chemical engineers in the past three years.
( ) = Number of respondents.

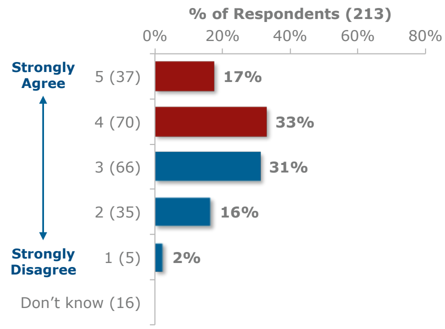
Academic Preparedness Opinions

Sr Non-Academic

While PhD graduates are viewed as being more prepared than BS/MS grads, there is still a number of respondents who feel they need more preparation.

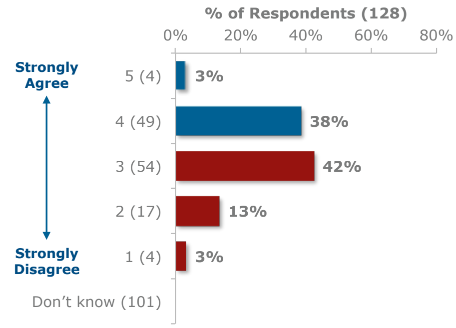
How strongly do you agree with the following statements? Please use a 5 point scale where 5 = Strongly Agree and 1 = Strongly Disagree.
(229 Respondents)*

Recently hired BS/MS graduates need more workplace preparation.



Top Two Box: 50%

Recently hired PhD graduates are prepared to meet the needs of the positions they are hired for.



Top Two Box: 41%

*Question asked only to non-academic respondents who have not hired chemical engineers in the past three years.
( ) = Number of respondents.

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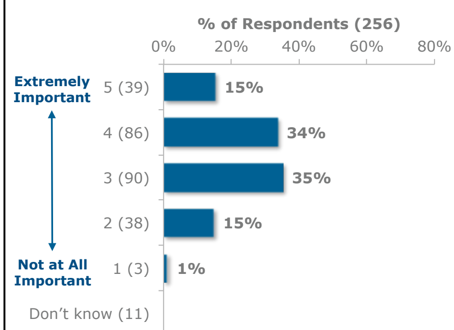
Position Skill Importance

Sr Non-Academic

As would be expected, expectations are slightly higher for PhD graduates.

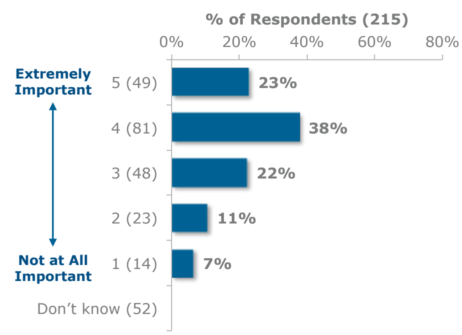
For each degree level, please indicate how important you believe it is for job candidates to possess the skills that directly match the position description. Please use a 5 point scale where 5 = Extremely Important and 1 = Not At All Important.
(267 Respondents)

ChE BS/MS graduates



Top Two Box: 49%

ChE PhD graduates



Top Two Box: 61%

( ) = Number of respondents.

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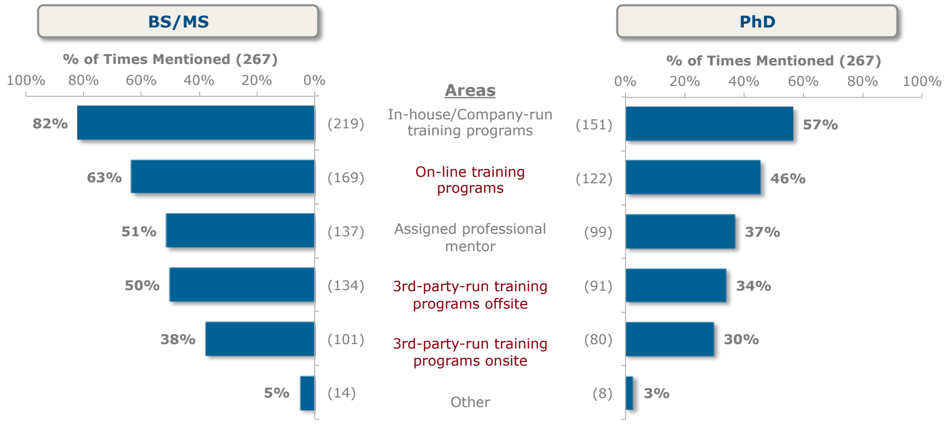
Offered Training Programs

Sr Non-Academic

More training is offered to BS/MS graduates than PhD graduates. Many locations take advantage of outsourcing some of this training to third parties or online sources.

For each degree level, what technical training programs, if any, do you offer for newly graduated hires?
(267 Respondents)



( ) = Number of respondents. Multiple responses accepted.

Subject Area Importance

Sr Non-Academic

Those in industry would rank the main chemical engineering subject areas as most important, followed by the business oriented subject areas, and lastly advanced chemical engineering, which has pretty low importance.

Please rate how important the following subject areas are in terms of career importance.
Please use a 5 point scale where 5 = Extremely Important and 1 = Not at All Important.
(267 Respondents)

Subject Areas	Importance Ratings 5	4	3	2	1	Average Importance
Core chemical engineering sciences	62%	28%	8%	1%	1%	4.48
Engineering and process knowledge	53%	35%	9%	2%	-	4.39
Math and chemical, physical, and biological sciences	45%	38%	15%	2%	-	4.27
Business, leadership, and project management	30%	42%	22%	5%	1%	3.96
Co-ops, internships, and/or faculty-supervised research	22%	38%	32%	7%	2%	3.72
Advanced chemical engineering	12%	25%	40%	18%	5%	3.23

*Subject areas were shortened to fit in the chart. Please refer to the questionnaire to see full text.

Academic Preparation PhD Opinions

Sr Non-Academic

Those in industry feel that PhD programs address all subject areas better than BS/MS programs do. Less than 50% of respondents feel that many of the current subject areas covered in Chemical Engineering programs prepare students for employment.

How strongly do you agree that present academic preparation for _______ programs addresses the following subject areas relative to employment need? Please use a 5 point scale where 5 = Strongly Agree and 1 = Strongly Disagree.
(267 Respondents)

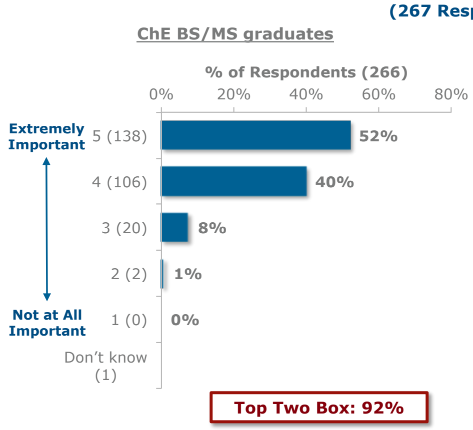
Subject Areas	BS/MS Top Two Box	PhD Top Two Box
Chemical sciences, including general, organic, physical, and biochemistry	79%	87%
Mathematics, calculus, linear algebra, differential equations	77%	85%
Fundamentals of thermodynamics, fluid mechanics, heat and mass transfer	75%	82%
Separation science and processes	52%	61%
Analysis and modeling, process simulation and optimization	43%	67%
Computational science and engineering	39%	62%
Process control theory and implementation	31%	43%
Data science and application: Design of experiments, statistics, analytics	29%	52%
Biotechnology and/or biomedical engineering	26%	43%
Material science, nanotechnology and polymers	23%	53%
Process and product safety	22%	22%
Business skills, leadership training, management, and economics	20%	21%
Innovation and entrepreneurial skills	14%	28%

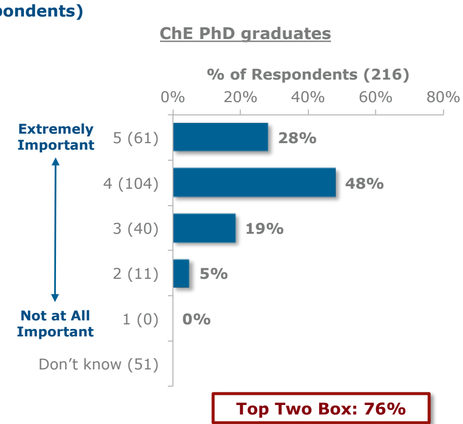
Practical Experience Importance

Sr Non-Academic

Practical experience is viewed as being more important for BS/MS graduates than PhD graduates.

How important is practical experience (e.g., internships, co-ops, international experience, prior technical jobs) for chemical-engineering BS/MS graduates and PhD graduates? Please use a 5 point scale where 5 = Extremely Important and 1 = Not At All Important.
(267 Respondents)





( ) = Number of respondents.

Reasons for Practical Experience Importance

Sr Non-Academic

Some reasons respondents do not think practical experience is important are: they will already have these skills based on their education, they will learn what they need to on the job and it will depend on the position they are hired for.

Why do you feel practical experience is not important for _________?*

ChE BS/MS graduates (2)

- *The most important skills gained through practical experience include time management and working in teams. Students learn these skills through their rigorous education/research.*
- *You get lots of on the job experience the first 5 years of your career.*

ChE PhD graduates (11)

- *Need for practical experience will vary greatly depending on career path. It is not as important for research/academic positions. Training associated with getting a PhD…should provide basics and knowledge of how to develop skills.*
- *PhDs should be experts in an area and hired for their expertise. Practical experience helps to establish this expertise, but is not required…*
- *Practical experience in the form of an internship is a 'nice to have', but not a 'need to have' for our PhD hires. The qualities that we are looking for in our PhD hires are technical leadership, deep understanding of Chemical Engineering fundamentals, ability to work independently, and demonstrated ability to solve a difficult technical problem.*
- *Specificity in a position.*
- *The most important skills gained through practical experience include time management and working in teams…*
- *The PhD program should give them strong skills already.*
- *The PhD research they do should be the practical experience they need since it takes 3-4 years to graduate adding to that would be difficult…*
- *They learn on the job.*
- *This role is more slanted towards creation of new products and processes. The creative element takes priority in the hiring decision and inherent technical abilities along with soft social skills and team work skills over "practical experience" as is defined here.*

*Question asked only to respondents who rated practical experience importance a "2" or "1".
( ) = Number of respondents.

Most Potential Growth Opportunities

Sr Non-Academic

A wide variety of areas were mentioned, none with an overwhelming number of responses. Energy is the area where the most growth is predicted.

In what areas of work do you see the most potential growth of career opportunities for students graduating with chemical engineering degrees?
(267 Respondents)

- **Energy (24)**
- Oil & gas (24)
- Environmental (19)
- Nanotechnology (15)
- Process safety (15)
- Biotechnology (14)
- Pharmaceuticals (13)
- Process design (13)
- **Alternative energy (12)**
- Petrochemical (11)
- Process engineering (10)
- Water/Wastewater (9)
- Materials science (8)
- Sustainability (8)
- Optimization (6)
- **Renewable energy (6)**
- Biochemistry (5)
- Business (5)
- New materials (5)
- Bioengineering (4)
- Data analysis (4)
- Food and beverage (4)
- Innovation (4)
- Management (4)
- Manufacturing (4)
- Petroleum (4)
- Project engineering (4)
- Separations (4)
- Specialty chemicals (4)
- Supervision (4)
- Biomedical (3)
- Green jobs (3)
- Project management (3)
- R&D (3)
- Reaction engineering (3)
- Technology management (3)
- Bio fields (2)
- Co-op work (2)
- Data simulation (2)
- Downstream chemicals (2)
- Field support (2)
- Lean manufacturing (2)
- Operations (2)
- Sales & marketing (2)
- Solids handling (2)
- Traditional chemical engineering roles (2)
- Advanced process (1)
- Applied materials (1)
- Biofuels (1)
- Biomechanical (1)
- Catalysts (1)
- Emerging technology (1)
- Lab technician (1)
- Life sciences (1)
- Natural gas processing (1)
- Practical implementation (1)
- Process development (1)
- Process integration (1)
- Process lead (1)
- Process operations (1)
- Process reliability (1)
- Production management (1)
- Scientific computing (1)
- Semiconductor (1)
- Six Sigma (1)
- Subsea flow assurance (1)
- Transport (1)
- All areas (3)
- Don't know (4)
- None (1)

( ) = Number of respondents. Multiple responses accepted.

JUNIOR NON-ACADEMIC (Bachelor's after 2000)

(237 Respondents)

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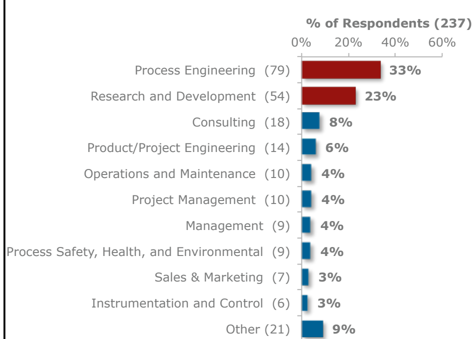
Job Function

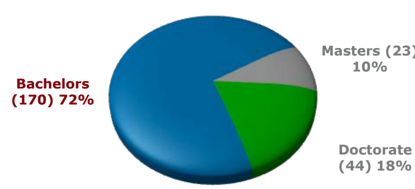
Jr Non-Academic

Similar to the seasoned professionals, Process Engineering and Research and Development make up the majority of the respondents. Almost three-fourths of respondents held only a bachelors degree when starting their jobs.

Which of the following best describes your job title/function?
(237 Respondents)



What degree did you hold when you began your job?
(237 Respondents)



Others include: Unemployed (3), Job Searching (2), Manufacturing (2), Process Simulation & Optimization (2), Quality Management (2), Analysis (1), Business Analyst (1), Facilities Engineer (1), Federal Safety Oversight (1), Government (1), Reservoir Engineer (1), Small business owner (1), Software (1), Technical Service (1), and Technology Training (1).

( ) = Number of respondents.

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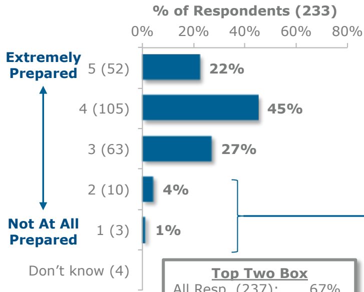
Education Value

Jr Non-Academic

Most respondents felt at least somewhat prepared for the jobs they were hired for. Many of those who did not feel prepared said it was due to lack of industry exposure/experience.

How well do you believe your education to that point had prepared you for the position you were hired into?
(237 Respondents)



Top Two Box

All Resp. (237):	67%
Bachelors (170)	67%
Masters (23)	65%
Doctorate (44)	70%

Describe how you were ill-prepared.

- *Before I graduated, I was told that an internship was not essential to obtain work. After I graduated, every place I have applied to denied my application on the basis of lack of experience...*
- *I did not have much information about chemical reactivity hazards and also I did not find a job in the field I did my PhD.*
- *I have knowledge of most engineering concepts, but my school failed to have enough industry style courses tailored to what might happen in the private sector. We only started these projects in my senior year, which was not enough time...*
- *I was provided insufficient information on how engineering functioned in industry... Also, I was completely uninformed as to what constituted the type of tasks an engineer would do...*
- *Laboratory work, sample preparation and analysis, and paper writing do not translate to applying for research positions within industry.*
- *Most of the valuable learning was gained on the job rather than via the classroom...*
- *Never received coaching or instructions how to integrate into the work force...*
- *I've had to learn almost everything on the job...I think that the thing that would have helped most would have been some kind of internship or coop experience.*
- *Technically I am very prepared. I received a great education at the University of Puerto Rico at Mayaguez. However, the industry life is very different. The development of soft skills and business skills are needed to work at the industry...*
- *Undergrad transport and reaction design and separations classes had entirely inadequate faculty without industry experience...*
- *Very little hands on work. Very little non-research examples/experiments were done.*
- *While classes did provide a foundation of basic engineering, it felt like we were simply checking off boxes on someone's list to prove the university was able to offer the curriculum...*

( ) = Number of respondents.

Additional Workplace Preparation Needed

Jr Non-Academic

The need for additional workplace preparation does not appear to be tied to the level of education received. Mentoring and self-instruction were the most common types of additional prep needed.

What types of additional workplace preparation, if any, did you need when starting your job?
(237 Respondents)

Additional Preparation	All Respondents (237)	Degree: Bachelors (170)	Degree: Masters (23)	Degree: Doctorate (44)
Professional mentoring (158)	67%	68%	61%	66%
Self-instruction (152)	64%	65%	65%	59%
Seminars (64)	27%	25%	30%	32%
Additional coursework (38)	16%	16%	17%	16%
On the job training (22)	9%	11%	9%	5%
Hands on experience/Internships (16)	7%	7%	13%	2%
Other (27)	11%	8%	26%	16%
No additional preparation (23)	10%	10%	4%	11%

( ) = Number of respondents or times mentioned. Multiple responses were accepted.

Training Activities

Jr Non-Academic

A vast majority of new hires have participated in in-house company training programs. The type of training is not tied to the level of education received.

As a new hire, did you engage in any of the following training activities?
(237 Respondents)

Activities	All Respondents (237)	Degree: Bachelors (170)	Degree: Masters (23)	Degree: Doctorate (44)
In-house/Company-run training programs (192)	81%	80%	83%	84%
On-line training programs (100)	42%	43%	26%	48%
Assigned professional mentor (93)	39%	43%	30%	30%
3rd-party-run training programs offsite (77)	32%	33%	39%	27%
3rd-party-run training programs onsite (61)	26%	28%	13%	25%
Other (8)	3%	4%	-	5%
None of the above (24)	10%	11%	9%	9%

( ) = Number of respondents or times mentioned. Multiple responses were accepted.

Subject Area Importance

Jr Non-Academic

New hires place greater importance on subjects like product safety and business skills compared to some of the other core chemical engineering subjects.

Based on your experience, please rate the following subject areas in terms of career importance. Please use a 5 point scale where 5 = Extremely Important and 1 = Not At All Important.
(237 Respondents)

Areas*	Importance Ratings: 5	4	3	2	1	Average Importance
Process and product safety	53%	29%	13%	4%	1%	4.30
Fundamentals of thermodynamics, fluid mechanics, heat and mass transfer	55%	23%	15%	6%	1%	4.24
Business skills, leadership training, management, and economics	47%	32%	16%	4%	-	4.22
Separation science and processes	32%	36%	19%	10%	3%	3.84
Analysis and modeling, process simulation and optimization	34%	30%	22%	11%	3%	3.82
Chemical sciences, including general, organic, physical, and biochemistry	27%	38%	22%	11%	2%	3.76
Data science and application: Design of experiments, statistics, analytics	29%	35%	19%	12%	6%	3.69
Mathematics, calculus, linear algebra, differential equations	24%	32%	29%	14%	2%	3.62
Innovation and entrepreneurial skills	25%	30%	24%	16%	6%	3.52
Process control theory and implementation	17%	35%	25%	17%	6%	3.39
Computational science and engineering	14%	22%	32%	21%	10%	3.08
Material science, nanotechnology and polymers	8%	22%	27%	30%	13%	2.81
Biotechnology and/or biomedical engineering	8%	8%	19%	28%	37%	2.24

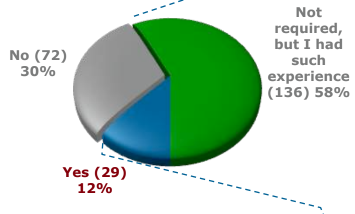
*Subject areas were shortened to fit in the chart. Please refer to the questionnaire to see full text.

Practical Experience Requirements

Jr Non-Academic

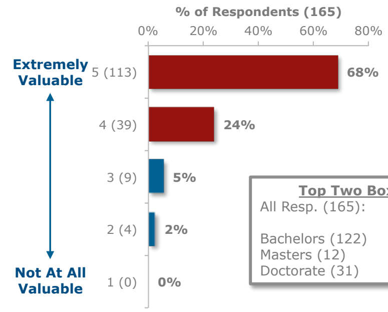
Very few respondents (12%) were required to complete practical experience as part of their program. Those who did complete it found it to be very or extremely valuable.

As a student, did your degree program require practical experience (e.g., internships, co-ops, prior technical jobs)?
(237 Respondents)



Degree	Yes	No	Not required, but I had such experience
Bachelors (170)	12%	28%	59%
Masters (23)	13%	48%	39%
Doctorate (44)	11%	30%	59%

How valuable did you consider that practical experience in preparing you for the workplace? Please use a 5-point scale where 5 = Extremely Valuable and 1 = Not At All Valuable.
(165 Respondents)



Top Two Box	
All Resp. (165):	92%
Bachelors (122)	91%
Masters (12)	100%
Doctorate (31)	94%

( ) = Number of respondents.

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IV. CONCLUSIONS

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Conclusions

Conclusion #1

There has been a shift in faculty's research interests in current chemical engineering programs.

Supporting Evidence

- ✓ 74% of academic respondents recognize the shift.
- ✓ 65% do not feel this is a short term trend.
- ✓ 58% feel this will cause drastic changes in the future.
- ✓ Faculty's research interests heavily affect the subjects they are willing to teach.
- ✓ Institutions are hiring adjunct faculty to cover specific courses and also offering full-time or tenure track positions to individuals with specific research interests to accommodate the shift.

Take Away

This is going to have an effect on the types of courses being taught in chemical engineering in the near future. It is also going to play a big role on institutions' hiring practices moving forward.

Conclusions (Cont.)

Conclusion #2

There is a lot value placed on having practical experience in the field of chemical engineering, yet very few institutions require it.

Supporting Evidence

- ✓ 92% of all respondents (academic, senior non-academic and junior non-academic) find practical experience to be very or extremely valuable for BS/MS graduates.
- ✓ 81% of senior non-academic respondents said they are more likely to hire someone if they have practical experience.
- ✓ Recently hired individuals who felt ill-prepared for the positions they were hired for related it to lack of industry exposure or experience.
- ✓ 88% of recently graduated respondents were not required to complete practical experience as part of their degree program.

Take Away

If institutions do not require practical experience, it could be very difficult for students to obtain, in turn making the job search more difficult.

Conclusions (Cont.)

Conclusion #3

Academic institutions do not feel there is as much need for workplace preparation as those in industry.

Supporting Evidence

- ✓ 71% of academic institutions feel that their undergraduates are extremely/very prepared for the positions they are hired for.
- ✓ And only 37% of academics feel BS students need more workplace preparation.
- ✓ Yet 50% of those in industry feel that recent BS/MS graduates need more workplace preparation.
- ✓ And 79% said that their recent hires did require some type of additional workplace prep.
- ✓ 90% of recently hired respondents said they needed some sort of additional workplace preparation when starting their current job.

Take Away

There is a discrepancy between academics and industry about how important/necessary workplace preparation is for recent graduates.