Paper ID #18644

Skills and Knowledge Important in Bioprocessing Design - A Survey of Practicing Engineers

Dr. Christine Kelly, Oregon State University

Dr. Kelly earned her BS in Chemical Engineering from the University of Arizona and her PhD in Chemical Engineering from the University of Tennessee. She served as an Assistant Professor for 6 years at Syracuse University, and has been an Associate Professor at Oregon State University in the School of Chemical, Biological and Environmental Engineering since 2004, where she also served for three and half years as the Associate Dean for Academic and Student Affairs of the College of Engineering.

Amy V. Nguyen, Oregon State University

Amy V. Nguyen is an honors undergraduate at Oregon State University studying Bioengineering with a minor in Spanish.

Skills and Knowledge Important in Bioprocessing Design – a Survey of Practicing Engineers

Introduction

Bioprocessing design includes optimizing unit operations in a process in order to attain a desired amount of product under economic, environmental, safety, quality, and other constraints. In the Bioengineering program at Oregon State University the students study both bioprocessing and bioproducts (focusing on biomedical) design in their senior year design sequence. This study investigated what skills and conceptual knowledge related to bioprocessing design and other courses in the curriculum were most important for entry-level engineers in the bioprocessing industry. A survey was created to examine which unit operations, technical skills, and professional skills were important based on the ratings from practicing engineers with at least 2 years of experience in the bioprocessing industry.

Surveys of bioprocess engineers have not been reported, but similar surveys for renewing and improving curriculum in the related field of chemical engineering are available. For example, the University of Sydney found that their curriculum should focus more on active learning techniques, constructive assessments that followed learning outcomes, and integrated learning with team teaching of modules. Their response was to revamp the curriculum to be highly integrated and focused on problem-based learning to develop transferable and conceptual skills (Gomes, et al., 2006). Another study at the University of Barcelona looked at adapting their chemical engineering curriculum to be more student-oriented and structured around the undergraduate and master's degrees. They changed their curriculum gradually to have more emphasis on ethics, feedback, and collaborative learning. Their findings were that although more time consuming, both students and teachers responded positively (Iborra, et al., 2014). A similar study was completed at Newcastle University, and resulted in using computer aided learning packages to promote enquiry-based learning by assigning tasks relevant to industry. Students reported improved conceptual understanding, teamwork abilities, and peer/self-assessment skills (Glassey and Novakovic, 2013).

Researchers Grant and Dickson (2006), on the other hand, looked at personal skill development in graduates to meet employer requirements through two surveys. Their findings were that chemical engineering graduates and their employers did not see entry-level engineers as meeting workforce requirements in transferable skills, but did have more than sufficient chemical engineering principles knowledge and subject-specific skill development. Grant and Dickson went on to suggest helping students develop transferable skills with project work or case studies.

The objective of conducting the survey were to gather information to help inform content decisions for the bioengineering curriculum and specifically the process design relevant courses in the curriculum (i.e. bioprocess design, bioreactors, and bioseparations. In addition, we wanted to use the feedback from practicing engineers to educate current students on the impact of the material they learn in their course work and how to increase their competitiveness in the job market. The results from this study informs and reinforces the emphasis we have seen in the past decade on developing professional skills in undergraduate programs, and indicates that we need to continue this effort. Insights from the technical skills and knowledge aspects of the survey will help fine tune the topics in our bioprocessing design and other topical courses (bioreactors, bioseparations, etc.) courses.

Methodology

The intended recipients of the survey were practicing engineers who had been employed as engineers for at least 2 years. They were recruited by email, letter, and social media posts (Facebook and LinkedIn groups). In addition, emails were sent to authors of abstracts from relevant national meetings. The survey was open for about 3 months (July-Sept. 2015).

The Qualtrics survey requested demographic information about the respondents' employers (type of facility, number of employees, number of engineers employed) and respondents' opinions regarding the skills, knowledge and experiences important for an entry-level bioprocess engineer (Tables 1, 2 and 3).

Table 1. *Survey design and operations knowledge*

• Process flow diagrams • Scale-up/design approaches • Equipment sizing and specification • Process control • Pumping and piping • Bioreactors • Bioreactor mathematical modeling • Bioreactor batch/fed-batch/continuous operations	• bioreactor design features (jackets, aeration, agitation) • Medium sterilization • Air sterilization • Biomass kill systems • Centrifuges • Microfiltration and ultrafiltration • Diafiltration • Chromatography • Virus and sterile filtration	• Conventional filtration • Crystallization • Heat exchangers • Cell lysis • Liquid-liquid extraction • Protein precipitation • Spray drying • Freeze drying • Formulation/filling/packaging

Table 2. *Technical and professional skills survey topics*

Technical Skills		**Professional Skills**	
• Programming • Statistics • Process economics	• Equipment costs • Manufacturing costs • Profitability	• Technical writing • Technical presentation • Project management • Interpersonal communication	• Ethics • Intellectual Property • Innovation/entrepreneurship

Table 3. *Experiences important for recent graduates' competitiveness in the job market*

• Grade point average • Industrial internship or work experience	• University internship or work experience • Study abroad	• Significant engagement in a professional student club

Results

There were a total of 31 respondents, but only 27 completed the survey. Twenty-five respondents indicated they worked for a pharmaceutical company, 13 for companies producing protein and enzymes, 2 for chemicals/polymers companies, 1 for a consulting/engineering company, and 2 for other (biofuels, biologics). Most (13) of the respondents were employed by companies with 100-500 employees. Only one was employed at a very small company (less than 10 people), and the remainder were employed at companies with more than 500 employees. Eight of the respondents were from California, 6 from Massachusetts, 5 from New York, and 1 or 2 from 7 other states.

The responses from the knowledge and skills sections of the survey (design and operation knowledge, technical skills, and professional skills) are ranked into five groups (Table 4) according to % of respondents that indicated that they are either important or critical for entry-level engineers. A summary of the respondents ratings are included in the appendix.

Table 4. *Respondent rankings of the three topics: design and operation, technical skills and professional skills in four groups by % ranking of the sum of important and critical responses*

92-100% of respondents ranked important or critical			
Interpersonal communication	Technical presentation	Technical writing	Ethics
56-70% of respondents ranked important or critical			
Statistics	Intellectual Property	Bioreactors	Process Economics
Innovation/ entrepreneurship	Bioreactor batch/fed-batch/continuous operations	Bioreactor design features (jackets, aeration, agitation)	Microfiltration and ultrafiltration
Process control	Process flow diagrams	Scale-up/design approaches	Diafiltration
Chromatography	Virus and sterile filtration	Design and operations	Conventional filtration
Project management			
36-48% of respondents ranked important or critical			
Equipment sizing and specification	Heat exchangers	Manufacturing costs	Pumping and piping
Programming	Medium sterilization		
24-33% of respondents ranked important or critical			
Formation/filling/ packaging	Bioreactor mathematical modeling	Centrifuges	Cell lysis
Air sterilization	Protein precipitation	Equipment costs	Profitability measures
Biomass kill systems			
4-16% of respondents ranked important or critical			
Crystallization	Freeze drying	Liquid-liquid extraction	Spray drying

Throughout the survey, there were several places where a respondent could select other, and insert comments. The respondent sometimes added comments that duplicated the topics that were in the survey. Table 5 includes the ‘other’ comments added by the respondents; with the number in parentheses indicating how many times the topic was mentioned.

Table 5. *Other topics suggested by respondents*

• Regulatory compliance (2) • Validation (3) • Statistical Analysis (2) • Design of Experiments (2) • Distribution • Efficiency /continuous improvement • Flow properties • Safety • Project management (3) • Thermodynamics • Lab skills • Processing software, e.g. UNICORN • Scale Down Approaches • Scientific techniques • Qualitative understanding of first principles	• P&IDs • Scheduling • Communication (4) • Presentation skills (3) • Leading meetings • Technical writing (4) • Professionalism • Working in teams • Resource budgeting people/materials • Cost per batch • Designing/implementing cost saving measures • Understanding what an entry level job looks like (not glamorous) • Interviewing skills • Pathways into the workforce

The final section of the survey asked respondents to rate which experiences or factors were most important for recent graduates' competitiveness in the job market. Respondents rated industrial internship or work experience the highest (85% respondents rating important or very important), and study abroad the lowest (7% rating important or very important) (Figure 1).

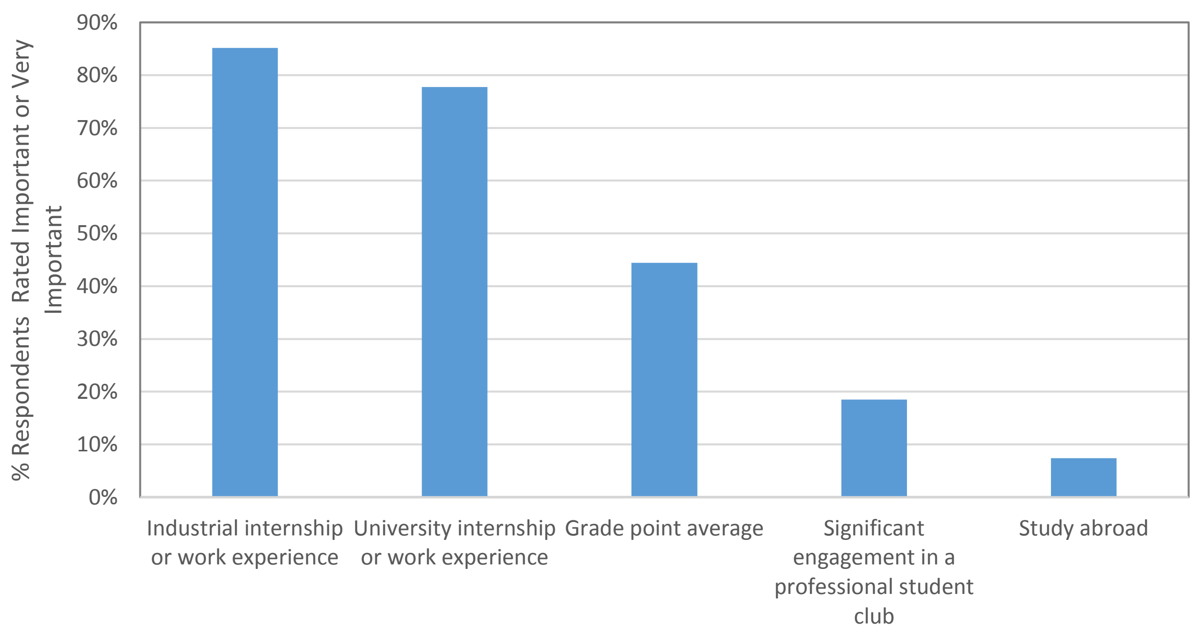

Figure 1. *Respondents rating on which experiences are most important for recent graduates' competitiveness in the job market.*

Respondent were able to add experiences, factors or reflections regarding competitiveness in the job-market for recent graduates. Table 6 indicates the comments from respondents.

Table 6. *Comments regarding experience contributing to job-market competitiveness*

• From my experience, there are many qualified candidates for a single position. On paper, most candidates will look the same. The difference comes when you are at an in-person interview and you must acknowledge something about yourself that makes you completely different from the other candidates; generally, this quality is not even related to work or academic experience. • Should be able to frame a problem. • No matter the position, being able to communicate well is critical, GPA can be used to thin a stack of resumes but I think most people realize it is a poor tool for selecting someone who will work well with the team. • For an entry-level engineer these items can be important during the initial screening but really only serve as a reference point to demonstrate their problem solving and interpersonal skills.

Discussion

The number of responses, 31, is quite low compared to our goal and the number of practicing bioprocessing engineers. In 2012 there were over 1.5 million engineers working in the US, including 18,810 biomedical and 32,190 chemical engineers (Sargent, 2014). The practicing bioprocess engineers are most likely a small subset of these two categories. Although we attempted to capture a large national audience through advertising on Linked In bioprocess professional pages, messaging large companies who employ practicing engineers, we believe most of the respondents came from former students in our bioengineering program and engineers who had a personal relationship with the author and their colleagues. The results cannot be extrapolated to represent a national perspective.

In general, professional skills were rated more important or critical than specific technical skills for entry level bioprocess engineers. However, this could also mean more university or broadly applicable across types of bioprocessing environments. Specifically, 92 -100% of respondents indicated that interpersonal communication, technical presentation, technical writing and ethics skills were important or critically important, while no technical skills fell in this range (Table 4). These four skills were the only topics (out of 40) that had zero respondents indicate that they could be learned on the job. In the additional comment sections (Table 5), professional skills were well represented, with communication and technical writing receiving four comments, even though both were represented in the Likert-scale sections of the survey. The seven professional skills were rated 1, 2, 3, 4, 6, 9 and 21 out of 40 skills and knowledge topics rated on the scale of % of respondents indicating important or critical for entry level engineers.

These results are similar to those reported in the literature. As mentioned previously, Grant and Dickson (2006) found from their surveys that most of the professional skills of entry-level chemical engineers did not meet industry standards according to the graduates themselves. A similar study looked at how the engineering field has and will change in the years to come due to globalization. The conclusions were that engineering graduates must further their communication, entrepreneurship, innovation, teamwork, and business skills along with their technical skills in order to be successful (Rajala, 2012). Along with this, the Department of Electrical and Computer Engineering and the College of Education at the University of Missouri introduced new courses to improve students' professional skills. Student surveys showed that previous coursework did not provide them with enough knowledge on these skills and highlighted the deficiency in some engineering curricula (Mohan and Merle, 2010). Alternatively, it has been proposed that curriculum-level changes be adopted rather than having a few specific courses on developing and applying technical and professional skills (Litzinger et al., 2011). Interestingly, DeMonbrun (2014) also found in initial results that more gender diversity in departments resulted in more professional values being taught throughout courses.

Practicing engineers rated statistics, bioreactors, process economics, microfiltration/ultrafiltration, process control and process flow diagrams the highest among the technical knowledge and skills topics. The interest in statistics is reinforced by the optional comments, which contained five references to statistics and design of experiments (Table 5). In addition to bioreactors, other unit operations that were rated highly included chromatography and conventional, virus and sterile filtration. Unit operations considered the least important to learn while a student included crystallization, freeze drying, liquid-liquid extraction, and spray drying. These selections may be biased towards the pharmaceutical industry, which employed the majority of the respondents. In the optional comments five respondents indicated that regulatory topics are important, and three suggested project management (although this was included in the Likert questions).

Respondent clearly valued industrial or university internship or work experience as a means to be competitive in the entry-level job market with over 78% of respondents selecting these as important or very important (Figure 1). In comparison, study abroad experience was only selected by 7% of respondents as important or very important. Compared to reported data in the literature, the value of some type of work experience for recent graduates' employability is similar. Stiwne and Jungert (2010), for instance, discussed the importance that engineering graduates placed on being able to carry out thesis projects at firms. This was not only for the experience, but also to develop key skills for the workplace, such as subject-specific knowledge, self-efficacy, and time management skills. A similar study looked at how the experiential learning that takes place in internships helps graduates' employability (Helyer and Lee, 2014). O'Leary (2014) goes on to say that internships not only improve competitiveness, but also give employers the chance to assess recruits for permanent employment.

On the other hand, this study found that study abroad was not important for recent bioprocessing graduates, when the available literature says otherwise. One study found that recruiters in the agricultural and natural resources industry (ANR) were interested in candidates with study abroad experience, for the interpersonal communication and leadership skills that would entail. However, respondents were also ambivalent towards global competencies, meaning the development of professional skills may be more important than the study-abroad experience itself. With this in mind, it is possible that the development of professional skills during an internship or work experience is seen as more applicable than from during a study abroad experience. Conversely, this difference in results may also stem from a difference in work area

(ANR vs. bioprocessing), where global and cultural competencies are viewed as less important for bioprocessing engineers.

Along with this, ABET Accreditation requirements have changed throughout the years to place more emphasis on the development of professional skills. In 1996, ABET began using *Engineering Criteria 2000* (EC2000) for the accreditation standards, which focuses on what students learn rather than what courses are taught. A three and a half year study conducted by Pennsylvania State University found that 2004 graduates were better prepared than 1994 graduates, and reported gaining more professional skills (through self-assessments). Another interesting finding is that although faculty were concerned with devoting more time to professional skills, students' self-assessments were higher in 2004 than in 1994, and they felt better prepared. Many in industry, especially from companies that recruit nationally, also report that they find new graduates' preparedness favorable (Volkwein et al., 2004).

Conclusion

This study examined which skills and knowledge are most important for entry-level bioprocess engineers according to practicing engineers. Although the number of respondents was low, their opinions corresponded with others' findings. Respondents consistently rated professional skills, such as interpersonal communication, technical presentation, and technical writing, highly. With regard to technical skills, the non-specific topic of statistics was rated most highly, with common bioprocessing unit operations, process economic and process flow diagrams ranked the next most important. Respondents valued work-experience to contribute to an entry-level engineer's job competitiveness.

References

1. DeMonbrun, M., & Brown, M. (2014, October). Emphasizing professional skills and professional values: Investigating the role of faculty's gender and departmental gender diversity. In *Frontiers in Education Conference (FIE), 2014 IEEE* (pp. 1-8). IEEE.

2. Glassey, J., Novakovic, K., & Parr, M. (2013). Enquiry based learning in chemical engineering curriculum supported by computer aided delivery. *Education for Chemical Engineers*, *8*(3), e87-e93.

3. Gomes, V. G., Barton, G. W., Petrie, J. G., Romagnoli, J., Holt, P., Abbas, A., Cohen, B., Harris, A.T., Haynes, B.S., Langrish, T.A.G., Orellana, J.,See, H.T., Valix, M., & White, D.. (2006). Chemical engineering curriculum renewal. *Education for Chemical Engineers*, *1*(1), 116-125.

4. Grant, C. D., & Dickson, B. R. (2006). Personal skills in chemical engineering graduates: the development of skills within degree programmes to meet the needs of employers. *Education for Chemical Engineers*, *1*(1), 23-29.

5. Helyer, R., & Lee, D. (2014). The role of work experience in the future employability of higher education graduates. *Higher Education Quarterly*, *68*(3), 348-372.

6. Iborra, M., Ramírez, E., Tejero, J., Bringué, R., Fité, C., & Cunill, F. (2014). Revamping of teaching–learning methodologies in laboratory subjects of the Chemical Engineering undergraduate degree of the University of Barcelona for their adjustment to the Bologna process. *Education for Chemical Engineers*, *9*(3), e43-e49.

7. Litzinger, T., Lattuca, L. R., Hadgraft, R., & Newstetter, W. (2011). Engineering education and the development of expertise. *Journal of Engineering Education*, *100*(1), 123-150.

8. Mohan, A., Merle, D., Jackson, C., Lannin, J., & Nair, S. S. (2010). Professional skills in the engineering curriculum. *IEEE Transactions on Education*, *53*(4), 562-571.

9. O'Leary, S. (2014). Incorporating employability into degree programmes by using consultancy projects as a form of international internship. In *Proceedings of the Global Internship Conference 8th Annual Conference* (pp. 173-176).
10. Rajala, S. A. (2012). Beyond 2020: Preparing engineers for the future. *Proceedings of the IEEE*, *100*(Special Centennial Issue), 1376-1383.

11. Sargent Jr, J. F. (2013). The US science and engineering workforce: Recent, current, and projected employment, wages, and unemployment.

12. Stiwne, E. E., & Jungert, T. (2010). Engineering students' experiences of transition from study to work. *Journal of Education and Work*, *23*(5), 417-437.

13. Volkwein, J. F., Lattuca, L. R., Terenzini, P. T., Strauss, L. C., & Sukhbaatar, J. A. V. Z. A. N. (2004). Engineering change: A study of the impact of EC2000. *International Journal of Engineering Education*, *20*(3), 318-328.

Appendix

Table A1. *Summary of respondents' ratings on knowledge, technical skills and professional skills*

Topic	Can learn on the job	Somewhat important	Important	Critical	Total	% Important or Critical
Interpersonal communication	0	0	7	20	27	100%
Technical presentation	0	1	9	17	27	96%
Technical writing	0	2	10	15	27	93%
Ethics	0	2	9	15	26	92%
Statistics	1	7	10	9	27	70%
Intellectual property	1	7	12	7	27	70%
Bioreactors	2	6	9	7	24	67%
Process economics	2	4	11	1	18	67%
Innovation/entrepreneurship	1	8	11	7	27	67%
Bioreactor batch/fed-batch/continuous operations	3	6	13	4	26	65%
Bioreactor design features (jackets, aeration, agitation)	2	7	12	5	26	65%
Microfiltration and ultrafiltration	3	7	13	4	27	63%
Process control	1	9	12	4	26	62%
Process flow diagrams	2	8	10	5	25	60%
Scale-up/design approaches	3	8	12	4	27	59%
Diafiltration	4	7	12	4	27	59%
Chromatography	2	9	8	8	27	59%
Virus and sterile filtration	5	6	11	5	27	59%
Design and operations	2	8	9	4	23	57%
Conventional filtration	4	8	14	1	27	56%
Project management	3	9	12	3	27	56%
Equipment sizing and specification	3	11	10	3	27	48%
Heat exchangers	5	11	7	4	27	41%
Manufacturing costs	8	8	11	0	27	41%
Pumping and piping	5	12	7	3	27	37%
Programming	3	14	8	2	27	37%
Medium sterilization	10	6	7	2	25	36%
Formation/filling/packaging	10	8	7	2	27	33%
Bioreactor mathematical modeling	7	11	8	0	26	31%
Centrifuges	9	9	7	1	26	31%
Cell lysis	8	11	8	0	27	30%

Air sterilization	12	6	6	1	25	28%
Protein precipitation	5	15	7	0	27	26%
Equipment costs	8	12	7	0	27	26%
Profitability measures	7	13	7	0	27	26%
Biomass kill systems	12	7	5	1	25	24%
Crystallization	13	8	4	0	25	16%
Freeze drying	15	9	1	2	27	11%
Liquid-liquid extraction	11	14	1	0	26	4%
Spray drying	17	8	1	0	26	4%