This column addresses aspects of lifelong learning for current students, alumni, and faculty. Examples of student and faculty activities that involve industrial practice and engagement as well as continuing education are welcome. These topics may not always lend themselves to the traditional scholarly format with formal assessment and extensive literature review but may be more editorial in nature. Submit papers through journals.flvc.org/cee, include lifelong learning in the title, and specify lifelong learning as the article type.

EDUCATIONAL INTENSIFICATION: A PARTNERSHIP BETWEEN INDUSTRY AND ACADEMIA

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INTRODUCTION

In the field of chemical engineering, differences exist between the needs of industry and training received during graduate or post-graduate studies.[1] One aspect is the necessary academic focus on theoretical solutions over practical application.[2,3] Differences are further aggravated by the inaccessibility of industrial researchers and research ideas, particularly on college campuses. Traditionally, a bridge between academia and industry is built by research partnerships, invited lectures, industrial internships, and graduate symposia.[4]

Well over half[5,6], and perhaps as many as 90%[4], of United States chemical engineering PhD graduates fill industrial roles after graduation. We postulate that increasing the interaction intensity between industrial practitioners and students better prepares the students for professional careers in many ways, including exposing them to the corporate work environment, teaching them various communication styles, and introducing them to practical technical approaches with commercial components.[4] We coin the term 'Educational Intensification' (EI) to describe intentionally increased interactions between students and industrial professionals (such as process engineers, researchers, and technical managers). Intensification comes from the added exposure and perspective gained from mingling these groups. The graduate students gain their theoretical and fundamental knowledge through coursework and thesis projects. This academic training is complemented by interactions with industrial researchers to gain more practical and applied experience. Our observation is that students exposed to EI are better prepared when they enter the workforce. Likewise, industrial researchers contributing to EI are better informed on the latest fundamental advances, gain diversified perspectives on current issues, and benefit from contributing back to the community.

While the traditional mechanisms of industrial and academic interactions provide some EI, we believe that more interaction channels would serve both parties well. In the remainder of this article, we present the need for enhanced interactions between industrial and academic researchers and describe the

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benefits to all parties: the graduate students, the faculty, and the industrial researchers. We comment on the benefits and challenges of the traditional interactions (research partnerships, invited lectures, internships, and graduate symposia) and provide advice for maximizing the value of those activities. Finally, we highlight two additional methods to increase these interactions: (1) teaching short courses at universities and academic conferences and (2) hosting faculty sabbaticals at industrial companies. We also believe that increasing EI is an effective path to overcoming relational barriers based on superficial factors, increasing opportunities and improving educational outcomes for a more diverse student population.

BACKGROUND

Over our combined five decades of experience identifying, recruiting, hiring, and training new team members for our industrial R&D organization, we experimented with numerous approaches to engage with the academic community. A common engagement activity occurs during yearly visits to a particular academic department for recruiting purposes. In such visits, we may schedule a series of meetings with selected professors based on their technical alignment with our organizational interests. In a day filled with 30-minute one-on-one discussions, we collect useful information on potential job candidates, but the faculty members benefit little aside from finding their students employment. These brief, infrequent meetings result in limited progress toward building trusting relationships founded on a two-way exchange. Furthermore, this approach does little to build relationships with the students.

Motivated by the axiom, "the more you put into it, the more you'll get out of it," we shifted our approach to fostering longer-term relationships with both graduate students and faculty.[7,8] We accomplished this by offering services to faculty and students to aid in their educational objectives. In the remainder of this article, we highlight the benefits and provide specific examples of this EI approach.

We target our services to complement the excellent graduate training received by our new hires. We focus much of our training on more practical and applied aspects of chemical engineering. A significant portion of a new employee's first year is focused on educating, training, and adopting safety standards required by industrial researchers.

BENEFITS OF EDUCATIONAL INTENSIFICATION

In Educational Intensification, the focus is on three basic people groups: students (here we focus on both graduate students and post-docs), faculty, and industrial researchers. The primary goal is to improve the educational outcomes for the students. We believe this goal is achieved directly and is self-evident. Beyond the primary goal, many other benefits accrue to the three groups.

Students

One obvious benefit to students is direct relationships with potential employers. The relationships and experiences can help students choose and secure jobs after graduation. During undergraduate education, many students participate in academic research and may have industrial internships. However, industrial internships are more limited during graduate education, so students often cannot compare academic research with industrial research. In particular, an internship gives the graduate student an opportunity to experience more applied research, which is typically more short-term focused than the fundamental research experienced in academia. Consequently, the industrial researcher must make decisions that are strongly influenced by timelines and value-driven deliverables, using all accessible resources within the company to inform those decisions based on a minimum expenditure of time and money. In addition, direct interactions with industrial representatives help students understand work expectations and company cultures. The added exposure better prepares the students for transitioning to an industrial setting. Therefore, an active and meaningful connection with industry equips students for determining whether they want to pursue an academic, industrial, or other career.

Also, interactions with individual industrial employees may lead to mentoring opportunities that are unique and difficult to establish without prior, more formal introductions. By diversifying and multiplying the interaction opportunities for students and industrial experts, EI provides more and better paths to meaningful and effective mentoring relationships than current practices. Furthermore, establishing strong relationships between the institutions provides a route to create meaningful mentoring opportunities for students that may not be assertive enough to seek out such opportunities on their own.

Through interactions with industrial researchers, students gain alternative perspectives on how to approach research challenges. Typical academic research is focused on theoretical and fundamental challenges and innovations. Interactions with industrial researchers flavor the theoretical developments with market considerations, raw material supply limitations, potential business strategic and tactical boundaries, and real-world operational constraints.[9] Many of the constraints include raw material availability, company focus, and profit. The successful researcher finds ways to creatively address innovation while subjected to these constraints. Furthermore, some students may crave more tangible feedback on the utility of their research that can typically only be real-

ized through industrial contacts (though start-up companies and other avenues do exist). Often, industrial researchers are required to focus on bigger-picture approaches and less on specific research details. In contrast, the students' main academic requirement is understanding the specific details of their research. Interactions with industrial researchers help the students step back and consider the broader implications of their work.

Many chemical engineering students tackle research problems that are peripherally related to the traditional scope of chemical engineering covered in the academic curriculum. While this is a positive consequence of the diversity of skills and methods developed and used by chemical engineers, an unintended consequence may be to exclude some students from developing skills or finding employment outside their thesis research. Again, the personal interactions and learning experiences that accompany our proposed approaches to EI can provide mechanisms to minimize these unintended consequences.

Finally, students gain exposure to alternative approaches to their research field or learn about new applications adjacent to the students' research.[10] Both opportunities broaden the students' approach and perspective during their doctoral work. This diversity of perspective can catalyze the removal of numerous barriers to creativity and innovation.

Faculty

Faculty also gain from the increased interaction with industrial partners. As relationships build, exposure to research opportunities, alternative approaches, and direct industrial needs become apparent to the faculty. Faculty can better align their research toward applications and get direct feedback on the economic and structural challenges to implementation. Faculty also gain affirmation on their direction and approach. Over longer periods, the increased interactions may lead to better-aligned research opportunities, including sponsored or co-sponsored research. The stronger relationship also allows the faculty members to vet new ideas before initiating larger research efforts. Grant proposal writing can be enhanced by additional comments and connections through the industrial partner. As the relationship strengthens, the joint development and targeted research become more probable and easier to initiate.

Additionally, the faculty can use EI as a differentiator in the doctoral candidate recruiting process. The department can emphasize its relationships with different industrial partners. Connections like short-courses, potential internships, collaborative research, and mentorship programs may entice top students to take advantage of the unique opportunities provided.

Industry

Finally, the industrial partner also benefits from EI. The industrial researcher is exposed to a broader scope and application of research. Typically, industrial researchers are limited to fields directly aligned to their company's stated core mission. Although critical, this limits the researchers from developing broad and cross-developmental ideas. Increased connections with academia allow industrial researchers to expand their thinking and diversify their research perspectives.

Additionally, collaborative efforts with university partners provide fertile ground for training and developing industrial researchers. We observe this development both in technical and soft skills.[11] For example, when a junior employee is asked to provide a lecture or short course for a university audience, the preparation to teach that material provides a development opportunity, as effective teaching requires a solid foundation of knowledge of the material.

Industrial researchers also benefit from earlier exposure to new technologies, approaches, and ideas. The pace of technological change is dizzying, and industrial knowledge of academic developments can be lacking.[12] Industrial researchers are tasked with recognizing, developing, and then implementing novel or improved ideas rapidly. The EI approach increases industrial researchers' awareness of new ideas and results. The combination of industrial application and academic fundamentals can help identify breakthroughs faster. As the academic researcher identifies the fundamental basis for development, the industrial researcher can point the developments toward application. This combination accelerates scientific development while enhancing industrial innovation.

As we originally discussed, one of the major goals for industrial partners in these relationships is to hire the best candidates for their organizations. Direct, prolonged interactions with students and faculty provide much more meaningful information than a curriculum vitae, cover letter, or letter of recommendation. With additional contact points, both the student and the industrial representative have opportunities to interact in a variety of social and scientific situations. Both parties develop a better understanding of each other's values, culture, and goals. The information is gathered more naturally, instead of through a forced, limited, and structured recruitment process. Furthermore, these connections enable a broader scope of interactions, where industry representatives gain exposure to new research fields while developing relationships that diversify the technical expertise in the hiring candidate pool.

One cannot discount the nostalgic value of the industrial-academic interactions. Many industrial researchers look back fondly on their graduate experience and long for similar connections. The zeal of research, the freshness of ideas, and the

limitless potential all surrounded by a campus atmosphere can provide an invigorating and emotional benefit to the industrial researcher. To be frank, the interactions with graduate and post-doctoral students are refreshing and rewarding.

METHODS OF INTERACTION

In this section, we describe both the traditional routes and a few uncommon approaches for industrial-academic interactions, focusing on the benefits and challenges of each approach. The list is not exhaustive. We propose EI to be a combination of these and other methods. Most importantly, the intensification results from the increased interaction with industrial contacts, both in the frequency and the relational intensity of these interactions.

Research Partnerships

Research partnerships integrate academic and industrial researchers working toward a common goal. Typically, the funding is from the industrial collaborator. However, the funding may come from other sources, and partnerships between collaborators may open new funding mechanisms. These partnerships can lead to rich and mutually beneficial efforts. In the best cases, the researchers are meeting on a regular frequency (such as monthly) where scientific progress and ideas are presented and debated. Most of the time, these meetings have been virtual, but we have found annual or biannual in-person meetings to be important for building and maintaining strong relationships. In some cases, relationships build beyond the formal progress meetings, leading to deeper and more fulfilling mentorships.

Challenges to this method generally align with an expected increased time commitment for both parties. A regular meeting frequency drives increased preparation time for all involved. If the faculty member and industrial researcher are not 100% aligned regarding research and development goals, the increased interaction may lead to confusion for the student. Another challenge is how to handle and report intellectual property.[1,7,8,13,14] Implementing a master agreement before initiating research significantly simplifies innovation ownership, reporting, and publications. However, the time and effort to develop fully executed master agreements can be long and challenging.

Invited Lectures or Seminars

Three different types of on-campus presentations by industrial representatives can enhance EI. One category is the invited seminar. The format or structure is not critical. Typically, the seminar is part of a regular department seminar series, sponsored by a multidisciplinary center, or as part of a research consortium. As the label implies, these seminars require an invitation, typically extended by a faculty member. We find these invitations to be an effective way for academia to open doors to industrial researchers.

A second category is the class lecture. Given the precious nature of classroom time, a professor is unlikely to give up a lecture slot to an industry expert without some prior relationship or knowledge of that expert's contribution. However, we find these opportunities to be instrumental in shaping students' recognition of course relevancy. Creating more of these opportunities requires initiative and a little risk-taking from both parties.

Finally, we periodically offer non-technical seminars, presentations, and panel discussions at numerous universities. This third category, being the most informal, can lead to healthy conversations that benefit students greatly. We tend to offer these informal seminars as a relatively easy addition to an otherwise planned campus visit, such as delivering a department seminar or recruiting. Topics typically address interviewing skills, work-life balance, choosing between graduate school and entering industry directly with a bachelor's degree, and the similarities and differences between industrial R&D roles and academic positions for students with doctoral degrees. Often, we initiate these non-technical seminars without an invitation by contacting student groups, department staff, or faculty members with our proposal and perhaps a request for assistance in advertising and managing session logistics. Partnering with affinity organizations such as SWE and NSBE or professional organizations like AIChE or ACS provides exposure for students and companies to a variety of opportunities. Seminars, courses, or panel discussions improve connections between students and potential career choices. By working with specific affinity groups, industrial teams can support the growth of diversity and inclusion at both the university and the industry.

The challenges associated with invited lectures and seminars are relatively small. The industry representative must prepare the material and obtain permission to travel and speak on that topic. However, the travel component can be overcome by pairing a lecture or seminar with a visit already scheduled for another purpose, such as recruiting or meetings for a research partnership. From the academic perspective, validating the level of expertise and credibility of a potential industrial speaker is often more difficult than with academic speakers. This may require creativity and effective networking by a faculty member seeking to sponsor a lecture or seminar by an industry expert, but the barrier is not insurmountable.

Internships

One of the most effective methods for EI is internships for graduate students. For more than a century, engineering undergraduate programs across the United States have

implemented and supported internships or co-op work. The time spent working for a company significantly enhances the students' appreciation for their studies and coursework. We observe similar benefits with internships for graduate students. Like undergraduate programs, the internship provides a completely immersive opportunity for the student to develop career skills while effectively interviewing the company for potential full-time employment.

A typical graduate student internship experience in Dow's R&D organization will consist of one dedicated research project.[15,16] That project is usually different from the student's thesis. Because the intern is a full employee of the company, the work is typically proprietary. Therefore, any resulting documentation remains within the company and is not included in the student's external curriculum vitae (but the experience and employment are certainly available for inclusion). The student benefits from the opportunity to explore areas outside of the student's thesis research. For example, someone focusing on experimental efforts for the PhD thesis may spend time developing mathematical models during an internship. Projects typically include partners from the host group as well as from other departments or functions. This allows the intern an opportunity to experience cross-disciplinary industrial research while building a broader network of contacts across the greater organization.

Our internships typically last 13 weeks. We find that this time is long enough for the interns to deliver meaningful contributions while not removing them from their thesis efforts too long. Sometimes, students are not able to participate in internships due to limitations from grants or funding sources. Additionally, since the intern is a full-time employee of Dow during the internship, the student must partner with the university to determine how to address the unique challenges associated with temporarily leaving employment at the university.

One of the major benefits we observe from internships is that they provide for a greater diversity of our team. We can take on students that come from a technical background outside our usual fields and observe their capabilities to learn a different area. Through the usual hiring channel, this evaluation is much more difficult and riskier.

Additionally, no matter where the students complete their internships, they tend to grow accustomed to the industrial work environment. After beginning full-time employment, graduate students that previously completed an internship tend to adapt more quickly to the programs, communication, and technologies used by companies.

Although graduate internships are extremely effective, they come with two significant challenges. The most obvious challenge is removing a graduate student from their main thesis focus. This absence can be difficult for the faculty advisor, particularly as the student reaches peak publication years. In some instances, we observe the graduate student taking 3 – 6 months longer to complete doctoral studies after completing a 13-week internship. In most cases, the faculty advisor inherits a more efficient and effective researcher upon returning from the internship. We believe capabilities developed by the interns outweigh the cost of the graduation delay. We encourage faculty members to be supportive of student internships.

The second challenge is the support the student requires as a new hire at the company. With a defined end date, the project scope must be identified before the student's arrival. Full-time employees must support the student through the onboarding process while helping the student navigate project obstacles, knowing the time limitations. Most importantly, designing the experience so that the student returns to school with a feeling of accomplishment requires a personal commitment not only from the program leader but also from individual researchers interacting with the student.

Graduate Symposia

An excellent way for industrial researchers to learn about current research programs and potential new hires is through a graduate symposium. Typical symposia sponsored by academic departments cover one or two days and include oral and poster presentations. The oral presentations allow the students to showcase their research while demonstrating their communication skills. Industry partners can ask questions, provide feedback (in some cases as judges), and mingle with students. Commonly, the symposia will include a lunch or dinner. The opportunity for relaxing conversations allows for more natural interpersonal relationships and less stressful conversations regarding work. Although the interactions are brief, the targeted quality of the discussions helps initiate new relationships. One innovation that can increase the EI of these symposia is to integrate presenters from industry into the program. This innovation increases the commitment of industry representatives to the success of the event by ensuring their active participation and provides an additional channel for technical discussions about industrial problems and priorities.

Short Courses

Over the last several years, Dow implemented an alternative method to connect academic institutions and industrial research: technical short courses. For example, several Dow teams have created and delivered (1) a laboratory reactor design short course with the stated goal to improve experimental data quality, (2) a series of about twenty lectures on industrial reaction engineering for the CISTAR NSF Engineering Research Center, (3) a multi-day course on statistics, (4) the Dow Lab Safety Academy, and (5) a case study workshop.[17] Having taught our lab reactor design short course at about a

dozen universities and a few technical conferences, we have found it very effective at providing a platform for meaningful dialogue leading to the establishment of substantive relationships between the industrial presenters and the students and faculty. We also foster the growth of technical skills and knowledge that we value in our employees, saving time for them to develop in those areas once employed. In this situation, both the university and the industrial participants benefit. The students and faculty gain knowledge specific to lab reactor design, while the industrial researchers gain connections with potential future employees, future collaborators, and future business partners. On more than one occasion, we received feedback from students that our lab reactor design short course changed the direction of their thesis research. The short courses Dow has provided address gaps that we perceive to exist in the academic curriculum. As indicated by the five examples provided earlier, these gaps can be generally classified as practical training. Except for our statistics course, the topics are less theoretical and mathematical. Instead, they require thinking that is more conceptual and typically rules-based. Even the presentation of our training on statistics leans in the direction of the practical, in contrast to a typical university course in statistics.

In our experience, the biggest barrier to effective short courses is preparation time for the industry experts. We have taken a few different approaches to overcome this challenge. One approach is to adapt an internal course already prepared. Generally, the effort focuses on removing proprietary information and adding case studies and information more generally known and applied.

Sabbaticals

Sabbaticals are an uncommon but valuable method of establishing relationships and enabling hands-on learning from one another. Academic and industrial careers tend to be insular, and few researchers have experience working in both environments.[13] In recent years, our team has hosted two professors for short (3-5 month) research sabbaticals. The professors worked on a few real industrial problems, provided consulting for other projects, and built their networks within our company while gaining a better understanding of the company culture. In one case, the sabbatical was a launching point for a collaborative effort to build a calculation tool for the broader research community.[18] This collaboration has led to an ongoing interaction between the industrial and academic partners as we have continued to maintain and even improve the tool, engaging multiple students directly with the industry partner over the ensuing years.

Our company has also sent researchers to the university campus for sabbaticals. This is extremely uncommon and tends to occur only in specific cases with unique opportunities and strong internal support from company leadership. As with faculty sabbaticals, industry sabbaticals can create new and lasting relationships that can lead to new ideas and fruitful collaborations.

RECAP

Research partnerships, invited lectures and seminars, internships, graduate symposia, short courses, and sabbaticals are a few methods that we have found effective at enabling EI. These activities allow students and faculty to observe the methods, styles, and technical breadth and depth of specific industrial organizations. In different ways, each of these methods reduces the barrier between graduate students and companies. By reducing that barrier, students and faculty gain a better understanding of the values, strategies, priorities, approaches, and cultures of those companies. The resulting EI benefits all three parties: students, faculty, and industry.

We have experienced the benefits of EI in our company firsthand. We hire many high-quality students who worked on our sponsored research projects. We also meet other students who share the same advisor but do not work on our sponsored research. We observe students effectively use internships to guide their career decision-making process, either to transition to industrial roles or to commit more fully to academic pursuits.

CALL TO ACTION

The University-Industry Demonstration Project (UIDP) has published resources to help researchers in both academia and industry establish new collaborative relationships.[19] We recommend these resources to those seeking advice regarding the next steps toward building these partnerships.

Academia

Because we believe that all parties benefit from EI, we urge leaders and influencers in the academic community to seek effective partnerships with industry experts. Many companies recognize and reward their employees for service to the educational community, so those industry experts may just need a nudge to provide an extremely valuable service to educators and students. We implore faculty members to be the catalysts for change by motivating their industrial colleagues to strive for increased engagement with academia.

Industry

We observe the benefits of EI and are committed to exploring new methods to reduce the gap between industry and academia. We implore our peers across the industries that employ chemical engineers to collaborate and innovate with

their partner universities. Progress will only be sustainable with a diversity of ideas, opportunities, and relationships. As more companies and individual industrial researchers contribute back to the community, the path for student development becomes a unified effort that enables increasingly diverse outcomes.

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