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Undergraduate Research in Chemical Engineering: Faculty Perspectives and Practices

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Introduction

Undergraduate research has been a common practice in many chemical engineering departments for many years with a first documentation in the chemical engineering education literature in 1981 [1]. At this time, the major focus of undergraduate research was as a tool to help increase the number of chemical engineering students in graduate school to address a concern about an impending decrease in chemical engineering faculty. Approximately one generation later, the Boyer Commission report provided recommendations on rethinking undergraduate education with a focus on inquiry-based learning [2]. The current approach in undergraduate research was developed from this recommendation, and undergraduate research is currently widely recognized as a "high impact practice"(HIP) [3]. Widespread university implementation of this HIP is due to its positive effects on recruitment and retention of students. Other benefits of undergraduate research include: research skills, the ability to think and work like a scientist, enhanced preparation for careers and graduate school, and personal and professional gains[4-6]. At the university and broader society level, undergraduate research can contribute to student continuation in STEM fields and graduate programs, and results for students in under-represented fields show higher benefits [7-12].

In contrast to studied and demonstrated benefits of undergraduate research for students, universities, and society, the benefits for the research mentors (including graduate students, post-doctoral scholars, and faculty) have not been as fully investigated. Several literature works do examine faculty motivation, outcomes, perspectives, and enabling and constraining factors [13-16]. However, these works were limited by the groups chosen for their surveys. For example, the study by Hayward et al. was only at one institution [13]. Jones and Davis looked at one liberal arts school and one R1 institution [14]. Morales et al. looked at a larger group of 13 research institutions [15]. Lastly, Morrison et al. examined three institutions, a private R3 university, a public masters college, and a private liberal arts school [16]. A more detailed compare/contrast of these works is presented in previous work [17].

To expand the results from the above works, learning more about why faculty participate as mentors as part of the undergraduate research process is important. The desire for undergraduate research opportunities does not appear to be abating. In order to partially address the need to include more undergraduate students in research, several approaches have been recently developed to group mentor students into the research process [18, 19]. Since it is also unlikely that current university faculties will grow to provide more opportunities, the focus then becomes better understanding why faculty contribute to this work so that the community can reward and acknowledge faculty in such a way that more faculty become aware of the benefits and potentially join and serve as research mentors. In addition, none of the above studies was discipline focused.

Thus, we have chosen to focus on the single discipline of chemical engineering in the United States. We have surveyed faculty on their perceived benefits and their perceived barriers while contributing to the undergraduate research process. This survey is across the spectrum of institutional types that have chemical engineering programs (R1, R2, other doctoral, master's, and baccalaureate). The goal of this work is to more systematically investigate the selected field in order to draw out lessons that may be applicable for implementation in other programs. A portion of this work examining benefits and barriers to these faculty was previously published [17]. In this work, we examine the data and discuss chemical engineering faculty perceptions of the specific benefits to the students and how the faculty interact with their students. Future work will break both sets of data down for further analysis to compare contrast any differences by institution type (for example R1, R2, and baccalaureate institutions), stage in faculty career (pre-tenure vs. post-tenure), along with statistical comparison to, for example, see if responses within a group are significantly higher or lower.

Methods

A survey was developed based on an instrument provided by Jones and Davis [14], with modifications that probed more specifically into the practices and perceptions of chemical engineering faculty. The survey was distributed to chemical engineering department chairs, with a request that they forward it to their faculty. The data collection, including the survey itself and our distribution methods, was approved by the Institutional Review Board at the University of South Alabama. A total of 110 faculty responses were received. Survey questions are included as an appendix in previous work [17].

Results and discussion

Faculty practices

As reported in the broader literature on undergraduate research and in our prior study of chemical engineering faculty, effective mentorship of undergraduate research is a time-intensive endeavor, and time constraints are a perceived barrier for faculty to engage undergraduates in their research programs. Given that context, we provided faculty with a list of common practices that mentorship might entail and asked them to rate the frequency with which they engage in them.

Some of the questions addressed mentorship practices that assist students in getting started on a research project. The responses to these prompts are shown in Figure 1. While all of the responses indicate that a significant majority of faculty do engage in all of the mentorship activities listed, a comparative analysis shows how faculty see their roles in the research preparation process. The two most frequently reported practices were explaining concepts and choosing models and methods. These represent more conceptual support than hands-on practice, providing the theoretical background to understand and plan the work. In contrast, the two items with the least positive frequency reported were planning experiments and teaching laboratory techniques. Because nearly 60% of the respondents were from R1 institutions and another 20% from R2 institutions, it is likely that the active training on experiments and laboratory techniques is carried out by graduate students and post-docs rather than the faculty mentors.

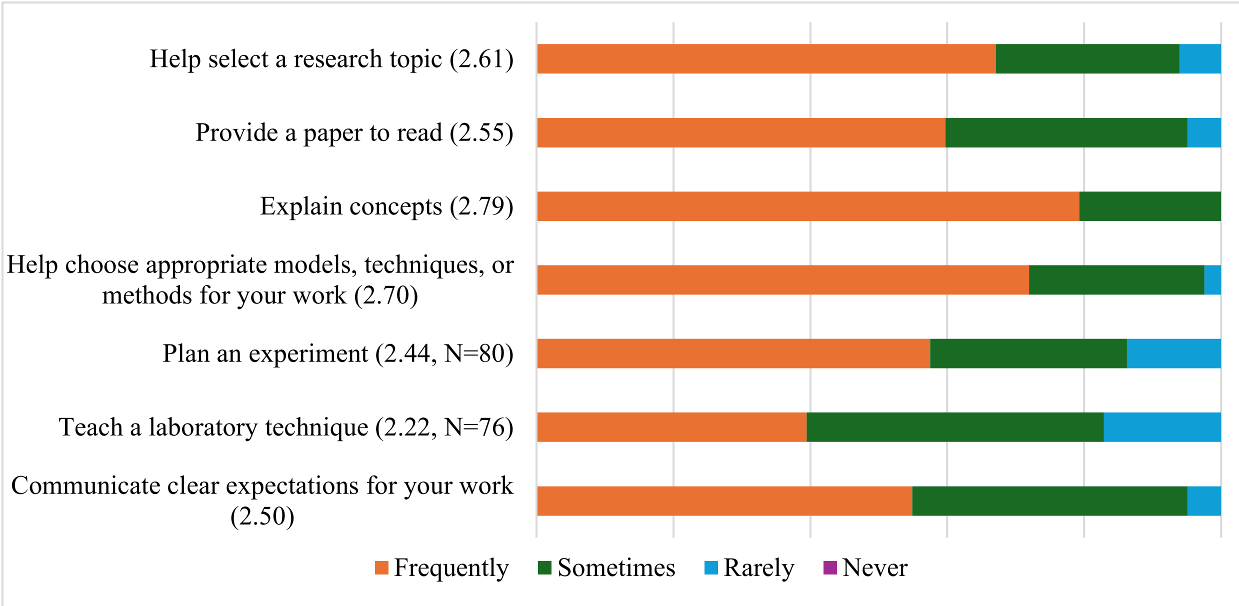

Figure 1. Distribution of responses on how often faculty engage in practices to prepare undergraduate researchers for their projects. Numbers in parentheses are weighted averages based on a scale from 0 (never) to 3 (frequently). Unless otherwise noted, *N*=82.

Another set of prompts can be classified as related to practices that support student progress as they are performing their projects. Results from these are shown in Figure 2. As a whole, this is the group that received the most responses of *Frequently*. Mentors report that they are regularly available to their undergraduate researchers, encouraging them to ask questions, and that they are frequently exerting effort to support the students to make progress in their

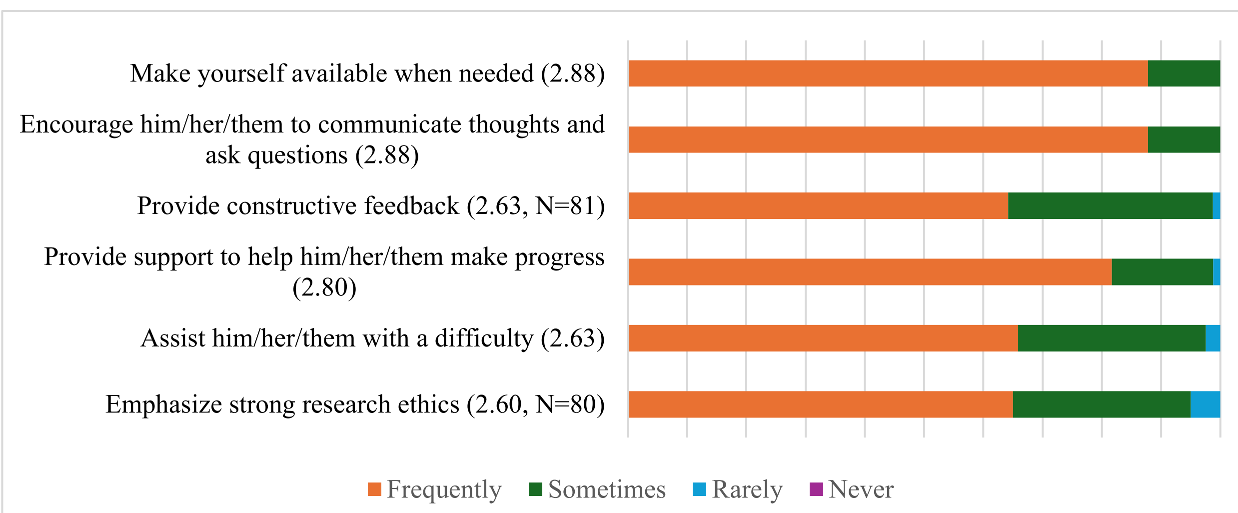

Figure 2. Distribution of responses on how often faculty engage in mentorship practices that help undergraduate researchers make progress in their projects. Numbers in parentheses are weighted averages based on a scale from 0 (never) to 3 (frequently). Unless otherwise noted, *N*=82.

research. Providing constructive feedback, assisting with difficulties, and emphasizing research ethics are reported as slightly less frequent practices, but it is possible that those practices are just less frequently necessary.

In the prompts on frequency of practices, the final grouping related to practices that prepare the students professionally, either in career planning or dissemination of their work, shown in Figure 3. Here it is evident that most faculty research mentors do not see themselves as academic advisors on curricular matters. This may be due to a shift of that responsibility to professional advisors in many institutions. More respondents do engage frequently in providing career and graduate school advice. Stemming from that is that more than 80% of them report frequent writing of letters of recommendation. They report less frequent reviewing of student work for disseminating results, but that is likely due to opportunities for dissemination being less frequent, as fewer than 10% report that they rarely do that. The most highly rated item in this section of the survey is treating students with respect, which promotes their professional development and encourages them to more proactively engage in their research.

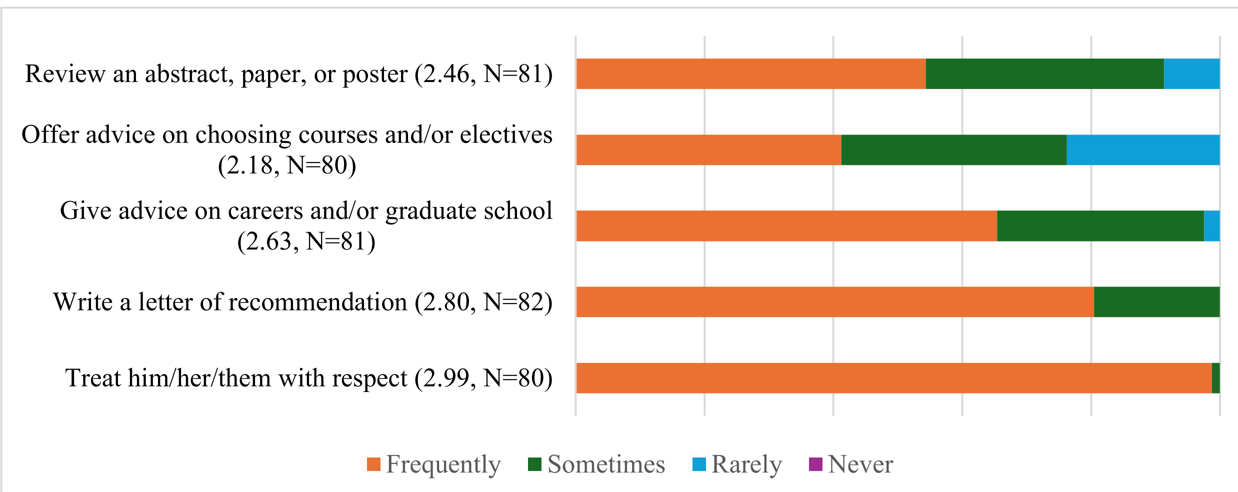

Figure 3. Distribution of responses on how often faculty engage in mentorship practices that support the professional development of their undergraduate researchers. Numbers in parentheses are weighted averages based on a scale from 0 (never) to 3 (frequently).

Put together (Figures 1, 2, and 3), these responses paint a picture of how chemical engineering faculty spend their time in undergraduate research mentorship. From project choice to dissemination, they are highly available to their mentees, in frequent communication to ensure the intellectual understanding of the project and supporting them through challenges so that they can make progress. They regularly provide advice and feedback on both the project and career plans. While this discussion has focused on comparison between items, it is important to note that only two items (giving curriculum advice and teaching laboratory techniques) yielded a response rate of *Frequently* below 50%. Both of these responses probably result from division of labor within the department. Curriculum advice is more likely to come from the student's academic advisor than their research mentor. As mentioned above, this data could indicate that direct laboratory supervisors such as a post-doc or a graduate student may take the lead demonstrating laboratory techniques. Differences in response rate for different institutions may also show up here (future work). That outcome affirms the previously reported result that time constraints are the most significant barrier to faculty for engaging in undergraduate research mentorship.

Faculty perceptions of student benefits

In our previous work, we found that the strongest motivating factor for chemical engineering faculty to include mentorship of undergraduates in their research programs was their belief that it was beneficial to the students. We posed a series of prompts based on the student benefits from undergraduate research participation that are documented in the literature. The prompts addressed the knowledge and skills, both intellectual and professional, that might develop as students engaged in research. To interpret the responses, it is important to note that the question asked was how important the mentors perceived the research experience to be to the development of the skills and knowledge. Thus, the results do not address the relative importance of the skills and knowledge or how well-developed they are in the students, but rather the role of the undergraduate research experience in developing them. These prompts were also thematically divided for comparisons. The themes are discussed below in order of increasing reported importance.

While all of the responses are quite positive, the theme that overall rated the lowest for importance of the research experience is development of chemical engineering knowledge, represented in Figure 4. Faculty likely expect students to bring some chemical engineering knowledge to the projects. Most highly rated in this grouping is the role of the project in comparing approaches to problem solving, the second prompt shown in Figure 4.

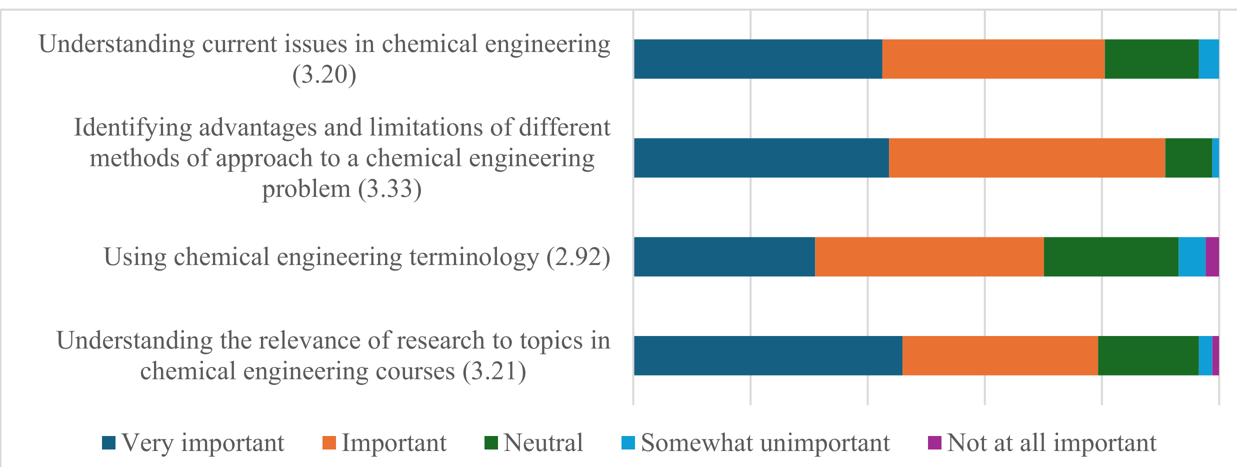

Figure 4. Distribution of faculty responses on the importance of the undergraduate research experience to enhancing chemical engineering knowledge. Numbers in parentheses are weighted averages based on a scale from 0 (Not at all important) to 4 (Very important). For all items, *N*=87.

The next highly rated set of questions address the importance of the undergraduate research experience in developing critical thinking skills, with the responses shown in Figure 5. Here the responses indicate that an important role of the students' work is learning to evaluate claims based on evidence, the second prompt in Figure 5. It is interesting to note, however, that the responses show a considerably lower importance of the research project on drawing conclusions based on personal beliefs. This might present an opportunity for instruction on the part of mentors or in undergraduate courses on research methods.

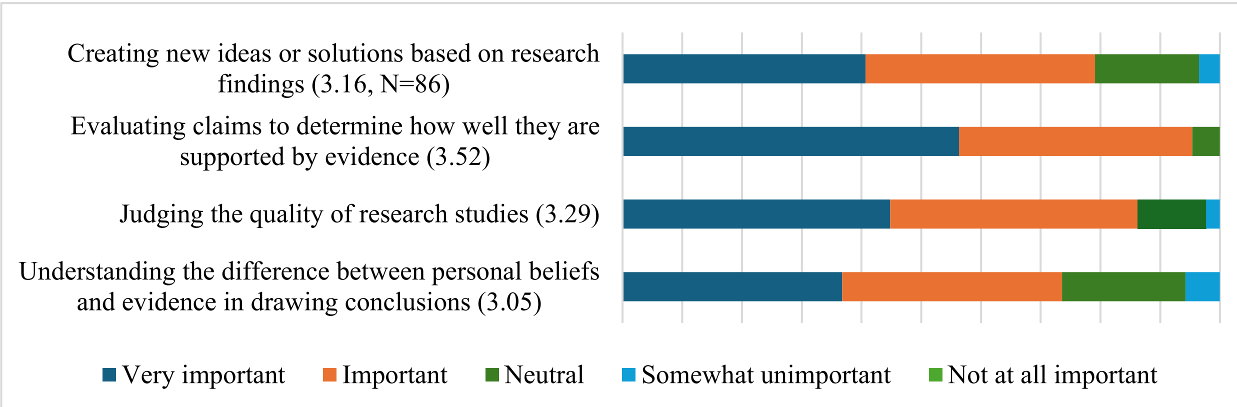

Figure 5. Distribution of faculty responses on the importance of their mentees' project to development of their critical thinking skills. Numbers in parentheses are weighted averages based on a scale from 0 (Not at all important) to 4 (Very important). Unless otherwise noted, *N*=87.

The next grouping of prompts, shown in Figure 6, represents the development of general knowledge on the research process. For these prompts, which are somewhat more specific than above, the importance of the research experience was rated somewhat higher than for critical thinking. Along that line, the most positive response in the group was on understanding the research process in chemical engineering, the second row of Figure 6. This appears to speak to the narrower scope, and possibly shorter timeframe, of undergraduate research projects compared to those of graduate students. It also indicates that mentors might serve their students by drawing stronger connections between the progress of the research process and the application of the scientific method.

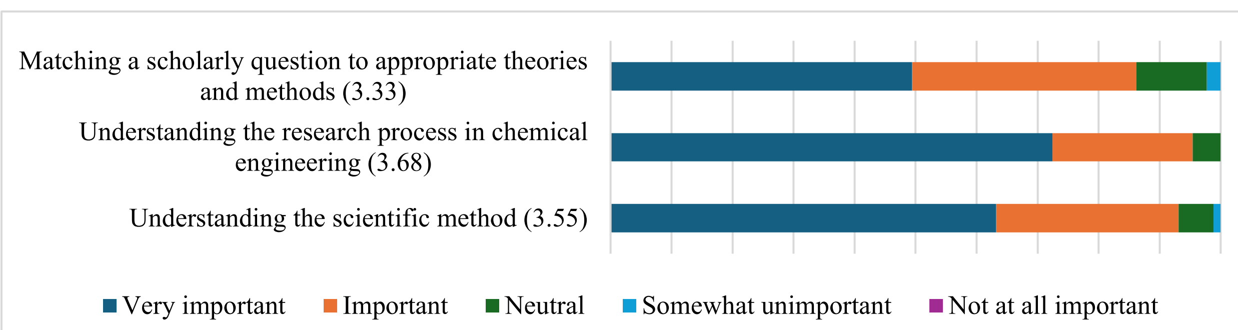

Figure 6. Distribution of faculty responses on the importance of their mentees' project to development of their knowledge of the research process. Numbers in parentheses are weighted averages based on a scale from 0 (Not at all important) to 4 (Very important). For all items, *N*=87.

The next group of questions turns from knowledge of the research process to practical research skills. The distribution of responses is shown in Figure 7. Here, respondents indicated that their students' projects are most important to their development of data analysis skills, the bottom row in Figure 7. While still highly rated, the reported importance role of the projects in developing skills at searching and reading the technical literature, the two upper rows, are markedly less than that of data analysis. It is interesting here to compare the result in the third row of Figure 7 on identifying appropriate data to answer a research question to the one on matching appropriate theories and methods shown at the top of Figure 6; identifying appropriate data scores markedly higher. This might be due to the more practical than theoretical nature of most undergraduate research projects. It is also notable that experimental design rated considerably lower than identifying appropriate data; it is possible that most undergraduate researchers are performing experiments that someone else designed.

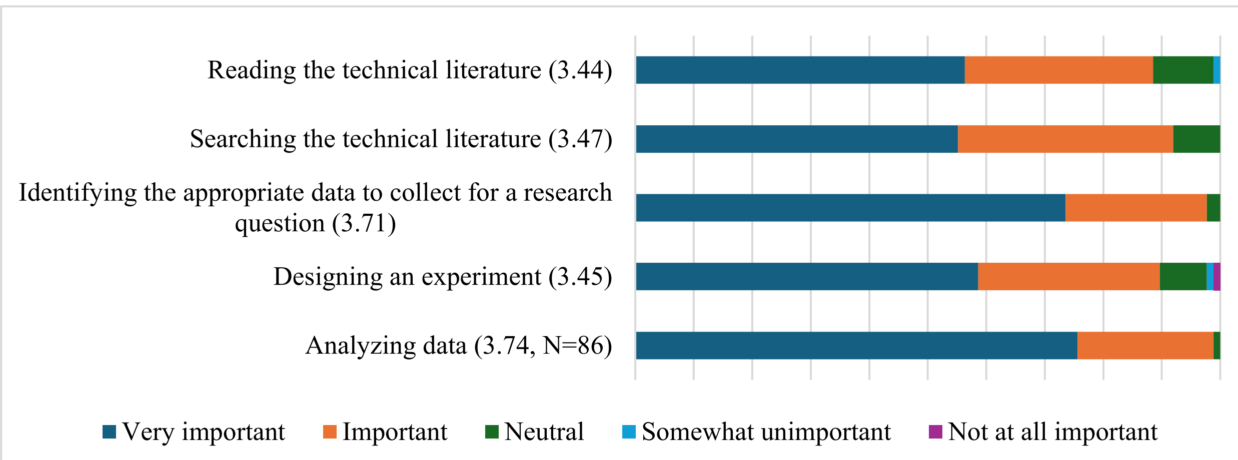

Figure 7. Distribution of faculty responses on the importance of their mentees' project to development of their general research skills. Numbers in parentheses are weighted averages based on a scale from 0 (Not at all important) to 4 (Very important). Unless otherwise noted, *N*=87.

Communication skills could be considered research skills, but are more broadly applicable. In a series of prompts related to developing communication skills, both formal and informal, faculty consider the role of the research experience to be highly important, as shown in the strongly positive responses to all prompts in Figure 8. This must indicate that the mentees are given ample opportunities to develop those skills, but in writing and oral presentations. That the student projects also build their skills in scholarly conversations likely results from their inclusion as part of a research group. In a separate question, 41% of mentors reported that undergraduates always attend their research group meetings, and another 40% reported that they usually do.

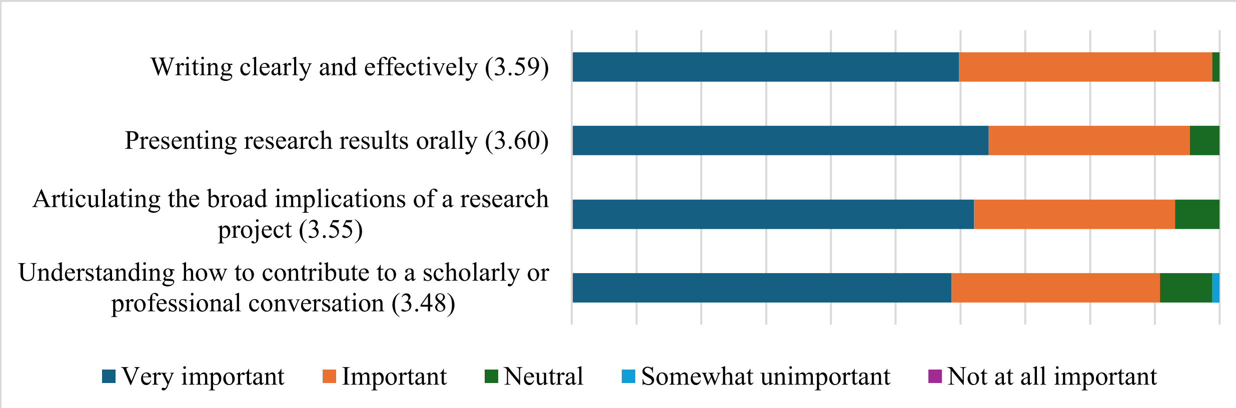

Figure 8. Distribution of faculty responses on the importance of their mentees' project to development of their technical communication skills. Numbers in parentheses are weighted averages based on a scale from 0 (Not at all important) to 4 (Very important). For all items, *N*=87.

Finally, some prompts address how the research experience might enhance skills that students will generally apply in their careers. Shown in Figure 9, this grouping was rated the highest, indicating that, above all, faculty believe that the research experience prepares students for whatever lies ahead of them professionally. Of particular note is the role of research in learning to deal with obstacles.

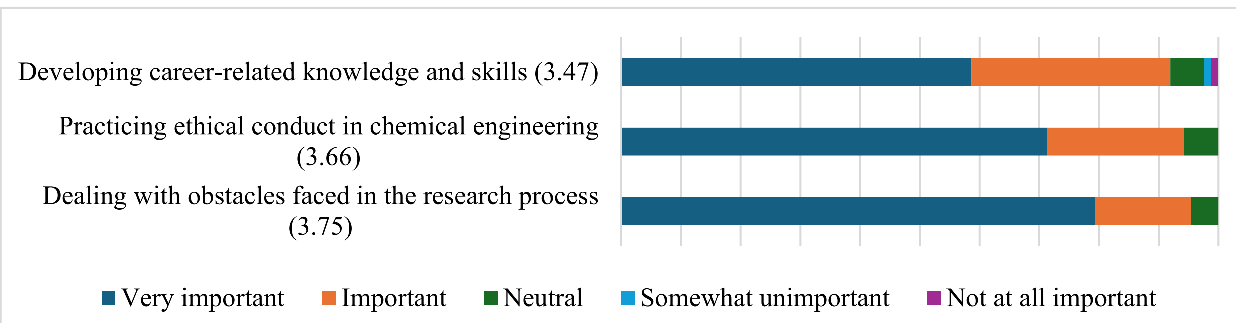

Figure 9. Distribution of faculty responses on the importance of their mentees' project to their career preparation. Numbers in parentheses are weighted averages based on a scale from 0 (Not at all important) to 4 (Very important). For all items, *N*=87.

Approaches to recruitment and selection of undergraduate researchers

Given the benefits to students that are documented in the literature and are motivating factors for mentors, how students are recruited and selected for research projects is important in maintaining inclusive practices in offering student opportunities. Respondents were asked how they recruited new undergraduate researchers, and the results are shown in Figure 10. The most common means of “recruiting” undergraduates is passive on the part of the mentors – students find them to ask about opportunities. While this does yield eager researchers for the faculty mentors, it probably means that the students who are finding the research opportunities are those who are most outgoing and "in the know." There may be students who would benefit most from the experience whose dispositions or backgrounds keep them from finding it. Identifying potential mentees in classes ranked the next highest. This practice can be inclusive of students who might be marginalized, but perhaps only if the faculty mentor is intentional about inclusion. The students who garner the most attention in class are often the same ones who are likely to knock on a faculty member's door. Much less common were the active approaches of advertising the opportunity and recruiting through student organizations. Most respondents who selected "Other" indicated that students working in their labs recruited other students. Chemical engineering departments where undergraduate research is prevalent would do well to build in program-level efforts to ensure that all students are aware of any openings for research experiences.

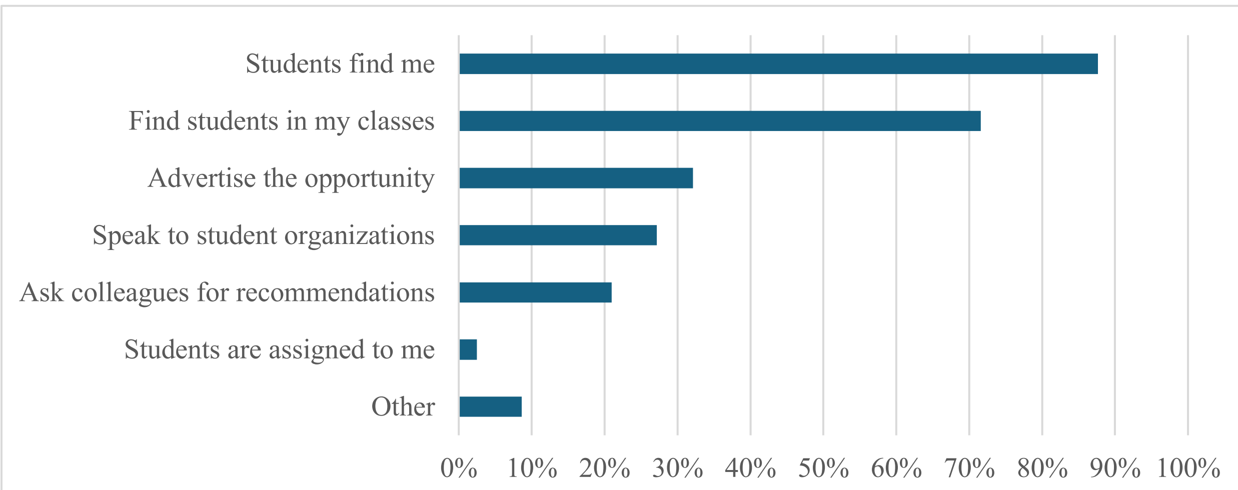

Figure 10. How faculty recruit undergraduates for research projects (*N*=81).

We also asked how faculty select the students who express interest in joining their research programs. Here, it appears that the mentors do thoughtfully discuss with the potential undergraduate researchers their interests, as that was by far the most highly rated criterion, with more than 85% of faculty considering demonstrated interest. The next highest was compatibility of expectations, which was considered by just under 50% of respondents. We note that outcomes for students and faculty, particularly in terms of research productivity, might be improved if more weight was given to those expectations. Because undergraduate research is often associated with academically exceptional students, it is interesting that slightly fewer than 40% of respondents reported considering academic records in selecting mentees.

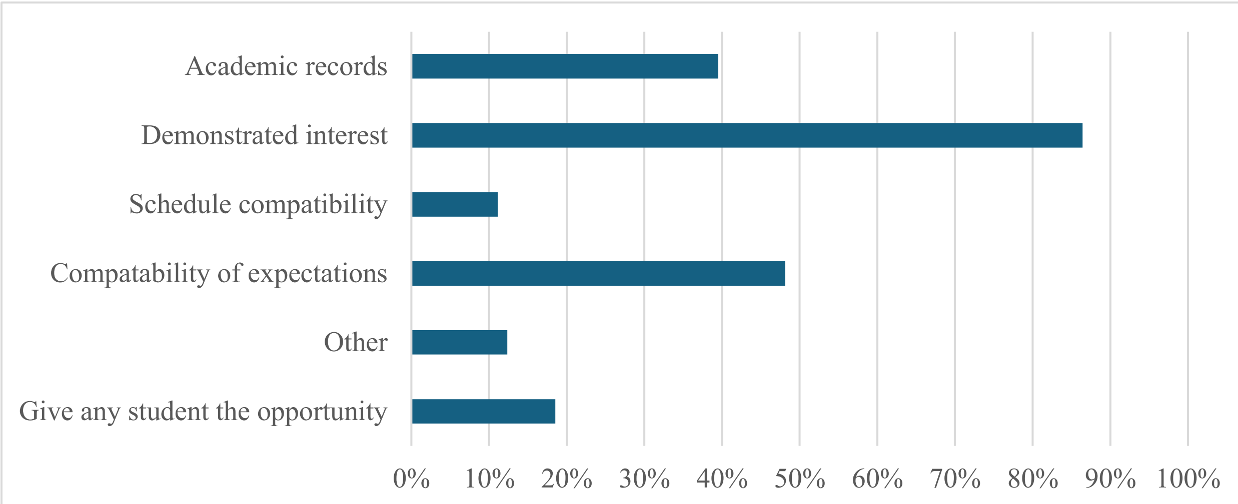

Figure 11. Criteria that faculty consider in selecting undergraduate research mentees (*N*=81)

Conclusions and recommendations

Following the previous report that chemical engineering faculty who engage in undergraduate research mentorship are most motivated by the benefits it offers to their students and most inhibited by the time that it requires [17], this study has probed how faculty spend that time and what benefits they believe are most yielded by the experiences they offer. They believe that the projects are most important in developing students' skills in research and communication and in preparation for their professional careers. The most time-intensive practices for mentors of undergraduate researchers are preparing the students for the project and supporting them as they make progress.

Departmental efforts could serve to maintain, grow, and enhance the undergraduate research experiences for chemical engineering students while supporting faculty productivity. Streamlining undergraduate researcher recruitment and training at the program level would reduce the faculty burden and promote inclusion. Creating a research methods and skills course offers a chance to deepen critical thinking related to research and improve skills related to both the technical literature and technical communication, while enhancing the research experience through cohort-building. Some departments have developed such courses, and find that they serve faculty both by reducing their time commitment and providing them with better prepared students [18, 19]. Awarding curricular credit for research with established, standardized expectations would build in accountability that might increase student productivity, in turn promoting faculty success.

Finally, departments are encouraged to recognize and reward faculty endeavors in undergraduate research mentorship. This includes acknowledgement of that work in promotion and tenure criteria as well as faculty workload. Additionally, departments should create awards for excellence in mentorship. Regardless of any monetary value of such awards, they publicly demonstrate appreciation for mentor efforts in providing students with opportunities to engage in this high-impact educational experience.

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