Contract No.:

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Workforce Development Survey Results:

industry, government laboratories, academia, and recent graduates

The TMS Education committee designated a subcommittee on Workforce Development to survey professionals in industry/government laboratories (I/G), academia (A), and recent graduates (RG) to gain insights into the alignment of materials science curricula with workforce needs. The survey project began with a charter to explore any disconnects that might exist between university materials curriculum and workforce knowledge, skill, and ability needs for MSE-related careers, and also highlight critical areas of excellence that should be preserved. Focused surveys for each category were developed and received over 150 responses, including 83 responses from industry/government, 40 responses from recent graduates, 29 responses from academia. The primary survey questions are summarized below, with choices for answers given in Table 1.

- Which of the following knowledge or skills have not been acquired by new hires?
- Which of the following knowledge or skills have been acquired by new hires?

The results of the category surveys are summarized in the following sections, highlighting noteworthy categories and comments.

Results

The results of the surveys are presented in three parts, starting with industry/government, followed by perspectives from new graduates themselves, and finally insights from academia.

Response from industry and government professionals involved in hiring and training new hires:

Experienced professionals from industry and government participated in this survey, including representatives from aerospace, automotive, energy, primary materials, sustainable materials, and suppliers. Specifically, the surveys were limited to professionals who participate in the new hire process and work force training, with a focus in the area of material science and metallurgy. A total of 83 responses were received for the survey, out of which 57% were from industry, 36% were from the government agencies, and other 7% were from other organizations, including safety regulators and trade associations. Most responses were received from professionals who identified with the energy sector (30%), followed by aerospace (14%), primary material production (11%) and automotive (6%). A combined 25% of the responses received were from other sectors including medical devices, defense, simulations, material informatics, electronics and the semiconductor industry. Overall, these employers indicated that they hire materials engineers from all three university degrees: bachelor's (B.S.), master's (M.S.), and doctorate (Ph.D.). Generally, industry indicated the hiring of more B.S. level graduates, with government laboratories hiring more M.S. and Ph.D. level graduates. Figure 1 presents results from the surveys summarizing the skill sets that recently hired new graduates do (Fig 1a) and do not (Fig 1b) possess.

The four areas where responses indicated new graduates have sufficient skill development included hands-on laboratory experience (42%), structure of materials (41%) computational approaches (37%), and mechanical behavior of solids (34%). Industry and government responses were similar, with the exception of structure of materials, which was indicated significantly more by government professionals, and mathematical foundations and statistical process control and design of experiments, which were indicated significantly more by industry professionals. Similarity between industry and government in this case also indicates similar outcomes for B.S., M.S., and Ph.D. graduates, based on general hiring practices mentioned previously, where industry tends to hire more toward the B.S. end of the spectrum, and government tends to hire more Ph.D. graduates.

Generally, it appears that materials curricula address most of the polled categories, with the only categories below 10% respondents consisting of failure analysis, non-technical professional development, and "other". In the "other" category, basic computer skills were listed by one respondent, and one added a comment that most B.S. graduates have learned to learn, but inevitably require further training wherever their career immediately takes them.

About 40% of both industry and the government professionals identified two major skills that are not adequately mastered by recent graduates, including effective oral (43%) and written (47%) communication. Typically, both undergraduate and graduate programs build these skills through oral presentations and report writing assignments in various courses during their studies. However, in order to create a qualified workforce, universities should provide courses that focus more on teaching foundational skills in professional writing and speaking needed for professional success. Additionally, data science, materials processing, statistical process control, and working across interdisciplinary teams were identified by >30% of respondents. Industry professionals also considered materials processing (47%) as important skill for new individual graduates to possess. The survey shows that hands-on laboratory experiences, materials design fundamentals, working across interdisciplinary teams, and statistical process control and design of experiments (SPC/DOE) are skills highly desired by government employers. Both government and industry professionals expressed that, working in an interdisciplinary team environment is a major skill needed to be developed in the new hires (41%). Energy, automotive, and aerospace-based professionals identified that failure analysis (24%), statistical process control and design of experiments (32%) were critical skills for new hires. It is to be noted that the above-mentioned industries not only perform failure analysis for parts/products in-service but also during the manufacturing of products to resolve process related issues. Statistical process control and product testing are key for many industries and assist management in the decision-making process. In the "other" category, specific skill areas listed included proposal writing, chemistry, economics, computer programming skills, and hands-on industrial work habits, and general areas included accuracy and deadlines, awareness of various materials areas (nuclear was noted), critical thinking, and understanding of which communication methods are commonly used (i.e., phone vs. email vs. text, etc. – perhaps generational issues).

Professionals from both industry and the government agencies both expressed that, once on the job, their organizations support and encourage the new hires continuous education and training on the job through a number of professional development programs, Figure 2. These training programs include external short courses, formal job training, mentorship programs, professional society participation and networking. These activities accounted for >60% of the major ways of supporting and on the job engagement of new hires. The independent study of various topics and tools were voted by the 50% of the survey respondents as important for a successful career path. Several respondents indicated also that internal training courses are available, and some organizations offer rotational programs to expose new graduates to the breadth of organizational activities. Continuing formal education in the form of an advanced degree from local colleges or universities was also included in possible avenues for advancement, but at least one respondent indicated that these activities might not result in advancement at their current organization.

General comments provide interesting insight into the responses outlined above, particularly with regard to communication skills. One respondent from a government entity indicated that communication skills were not entirely absent during the academia training (??), but perhaps do not fully encompass the daily activities of a practicing engineer, including reading and reviewing technical reports, writing requests for proposals (RFPs), evaluating proposals, writing technical reports, and delivering formal and informal presentations. Another respondent from industry indicated that the ability to capture all relevant details in a concise, succinct and thorough manner in a report is rarely seen in new graduates. These suggests that it is likely that not much time is spent in undergraduate programs developing writing skills for the breadth of document types and audiences that young engineers will encounter.

An interesting comment from an industry respondent was that their organization does not generally hire materials engineers but focuses on engineers from other disciplines. Although the reasons behind the decision were not indicated, this may be due to a lack of resources to have focused materials engineers in their organization and may indicate today's engineers need to have broader skillsets than may have been required in the past.

Diversity was also mentioned as a big challenge, as a lack of a diverse pipeline from universities results in challenges for organizations to hire a diverse workforce. This suggests that further efforts are needed to improve diversity when recruiting students to university education programs is necessary.

Response from recent graduates who have entered the workforce within the past 3 years:

A similar survey was taken by recent graduates to identify their learning experiences in the material science/metallurgy programs. Forty-one (41) recent graduates participated in the survey. Among them, 68% had Ph.D.'s, 15% M.S., and 17% B.S. These graduates identified with various economic sectors, including energy (20%), primary materials (15%), automotive (10%) and aerospace (10%). The vast majority of the new hires were now in academia (15%) or industry segments and government agencies (30%). The remaining 45% indicated "other" areas that were not specifically listed on the survey choices, including defense, minerals processing, medical /pharma, and government research. The responses were separated into highest degree achieved. Figure 3 presents results from the surveys summarizing the skill sets that recently hired new graduates do (Fig 3a) and do not (Fig 3b) acquire.

The top areas where recent graduates felt their degree program gave them the skills necessary to succeed in their career were hands-on laboratory experience, effective written communication, materials processing, effective oral communication, mechanical behavior of solids, and structure of materials. Responses were generally similar regardless of highest degree achieved, particularly considering the relatively low number of respondents whose highest degrees were B.S. or M.S. Surprisingly, the new hires generally expressed that they possessed adequate oral and written communication skills to perform their new jobs which completely contradicts the impressions of the experienced professionals (managers, executives, directors, etc.) that hired them, see Figure 1.

Generally, it appears that materials curricula address most of the skill categories that were listed on the survey, with very few indicating “other”. In fact, the only respondent including another category here was a Ph.D. graduate suggesting that some more specific knowledge in their specific discipline would be helpful. The categories with the lowest response levels were SPC/DOE, modeling and simulation tools, non-technical professional development, computational approaches, and data science.

Recent graduates expressed the importance of having additional information technology/computational technical skills that allow them to pursue a successful career path in government, industry, or in academia. The skill deficits identified by these recent graduates included computational approaches (45%), data science (39%), modelling and simulation tools (39%). In alignment with experienced professionals, 42% of the recent graduates responded that statistical process control and design of experiments should be more emphasized in undergraduate programs.

Approximately 70% of recent graduates responded that independent study topics/tools were helpful supplements to their undergraduate studies, Figure 4. Recent graduates also responded that informal discussions with colleagues (60%), formal job training (51%) and external short courses and training (49%) were activities that helped them improve their new job performance. Around 30% of the recent graduates also noted that professional society participation and networking provides good supplemental education and training.

Additional anecdotal comments from recent graduate respondents may be useful in providing some context to the above data. One respondent indicated that, for themselves and other recent hires they have known, there are educational gaps in new techniques being developed in industry, including computational engineering, modelling, and simulation, and that just a few of their fellow new hires had formal introductions to these important topics. Statistical process control and design of experiments was also an area specifically mentioned by a respondent in the additional comments, particularly for those seeking industry careers, and another suggested that their undergraduate program did not necessarily focus on some of the skills that were useful in industry, but instead on skills for those who subsequently pursue advanced degrees.

The experiential components of an undergraduate education were highlighted in one comment, suggesting that participation in undergraduate research opportunities not only allowed them to gain experience, but also have a better view of which aspects of the field the student found interesting and engaging. Others found that the professional development opportunities in their undergraduate program were limited and resulted in most graduates accepting positions at the same employers that supported the program, year after year.

For those entering graduate programs, materials engineering programs might benefit from some type of “bridge” from undergraduate engineering to maximize opportunities for recruitment, as one respondent noted the challenges associated with pursuing an advanced degree in one area after completing a BS in another area. They found that substantial independent study helped them overcome the “imposter syndrome” they initially felt, and also indicated that their most salient competency was not knowledge or skill-based but rooted in the critical thinking abilities they developed during their undergraduate experience. Finally, a respondent indicated that knowledge in materials engineering is important, but additional skillsets in management of people would have been quite beneficial in their career.

Response from academic professionals involved in hiring and training new hires:

The respondents to the academic survey indicated they are generally (64%) highly engaged in curriculum development for the materials science or materials engineering program at their university and represented over 16 materials programs from US universities. When considering their own program, most respondents indicated structure of materials, hands-on laboratory experience, and mechanical behavior of materials were skills that incoming graduate students possess, and that effective written communication, effective oral communication, data science, and computational approaches could benefit from further development, Figures 5a and 5b. Importantly, the areas indicated in both of these charts are in generally in alignment, suggesting that the greatest opportunities for augmenting materials engineering programs lie in the computational and data science areas, which is further corroborated by Figure 6a, which suggests the areas that faculty would insert of further emphasize in curricula, given the opportunity. Given the indications from industry, government, recent graduates, and academia that computational and data science need further attention in materials engineering curricula, the primary challenge seems to be how to manage this while maintaining the current strengths in curricula.

The final survey question to academia posed which changes occurring in materials engineering departments will affect faculty ability to address preparation of future materials workforce, Figure 6b. Unsurprisingly, the impacts of the current global pandemic garnered the most responses, but the availability of funding, the increase in student populations, and limitations in laboratory space each garnered a significant number of responses. Several interesting "other" responses included (1) growing faculty and institutional focus on research limits dedication to pedagogy and educational development, (2) competition with disciplines such as computer science may challenge smaller disciplines such as materials engineering, (3) declining faculty numbers may be a challenge to overcome, and (4) priority differences among faculty and visions for the future workforce may dilute materials education.

Two general comments from academia respondents also provided some further context. First, one challenge in educating the materials engineering workforce is that career paths are bimodal, where some graduates go to an industrial (largely manufacturing) environment and subsequently proceed on a managerial track, whereas others go on the graduate school path and end up in dedicated research roles at national laboratories or in academia. It was noted that the skillsets required for these two paths is quite different. Some comfort may be taken from the results of this survey regarding this concern, as nearly all respondents from all employment categories identified communication and computational/data science as the main areas that need to be enhanced in materials engineering curricula. Second, echoed from above, is that materials faculty tend to lean toward research-intensive careers, and that research in specialized areas or faculty that are less interested in undergraduate education both undermine efforts to provide undergraduates with a strong materials engineering foundation that is sufficiently broad to allow career flexibility.

Summary

The survey results presented here suggests that current university materials engineering curricula are successfully training the workforce in many areas, including hands-on laboratory experiences, structure of materials, mechanical behavior of solids, and some computational and modeling/simulation competencies. However, the primary areas identified in this survey where materials engineering curricula could be further enhanced include communication and computational/data science skills. The ability to think critically was also acknowledged as a skill that enabled individuals to add flexibility to their career choices, as adapting to a new area becomes much easier with these skills. A significant highlight of materials engineering curricula coupled with hands-on laboratory experiences often translate to real-world successful careers, but there is concern that laboratory practices at the university level are some way behind in the precision, documentation, and safety considerations that have become standard in industry and government facilities.

The feedback from industry and government professionals regarding a general lack of adequate communication skills in recent graduates is quite interesting, as their feedback contradicts this assessment and believed that they are proficient. This apparent discrepancy may not be that surprising, however, when considering that the bulk of communication assignments in undergraduate courses are focused on laboratory reports (laboratory courses) and project presentations (senior design/capstone), whereas the breadth of communication routes and audiences significantly increases upon entering industry, government laboratories, or even graduate school. It may be worth considering new strategies and assessments on how to incorporate more diverse writing assignments for various audiences into undergraduate courses. Some suggestions have been included above but should not be considered comprehensive. A specific challenge in enhancing the undergraduate curriculum with respect to communication is the general trend of teaching larger class sizes which results in limited individual interactions and detailed critiques of student communications by faculty or even graduate students. That is. the larger the class, the more communication is evaluated based on rigid metrics and practices, which may hinder student's ability to perfect and growth communication skills. It is currently rare that undergraduates critique the communication style of their peers or are requested to evaluate professional publications. One solution might be to ask undergraduates to regularly assess the writing and oral communications of themselves and others. With teleworking activities being more prevalent these days, students could also record themselves and asses their skills. This may give further perspective on effective communication and how to appropriately adjust communications practices for a given medium or audience. This approach may be more effective as class sizes increase. Finally, it could be beneficial to teach writing and oral communication in a manner that suggests these are areas that can and should be continuously developed and reshaped throughout a given career.

An area of significant concern expressed by recent graduates was that they did not have a clear understanding of career options and opportunities. Although many undergraduate curricula include discussions of career options and universities are equipped with career centers, it appears that additional connections are needed between scholarly activities and career paths in industry, government and academia. Further discussion of career options or internship opportunities seems necessary, and perhaps communication and experiences of what to expect from a job in industry, at a national laboratory, or at a university. Better communication of these opportunities, including how to apply for a professional position or graduate school, would be beneficial, including further discussion on engineering graduate school norms (such as stipend, tuition, health insurance paid). Materials is a field that isn't introduced until after high-school, and students may be overwhelmed with the various areas of opportunity. TMS has five divisions – Extractive & Processing, Functional, Light Metals, Materials Processing & Manufacturing, Structural Materials – and within them nearly 40 committees focusing on various materials areas. Undergraduate students are unlikely to really understand the details of these areas. However, programs such as Material Advantage can go a long way toward exposing undergraduates to a wide range of industry and government professionals through local interactions and seminars, and the ability to attend conferences such as the TMS annual meeting, which provides broad exposure to the materials community. TMS also offers many opportunities for recent graduates, including the Young Professionals committee, the Emerging Leaders Alliance program, the Professional Development award, the International Scholar program, and the Early Career Faculty Fellow award. In addition, there are many resources that expand individual's knowledge of the materials field, including TMS events, a webinar library, webinar presentations, mentorship programs, professional registration, the Professional Engineering (PE) exam study guide, volunteer opportunities, and the JOM job board. TMS is also dedicated to being a highly inclusive society where all materials students and professionals feel welcome, and diversity is celebrated, suggesting that participation by students, professionals, and academic faculty could help address some diversity challenges. The TMS Diversity, Equity, and Inclusion committee is active, growing, and enthusiastically welcoming new volunteers. The Diversity in the Minerals, Metals, and Materials Professions 4 (DMMM4) conference will be co-located with the 2021 TMS Annual Meeting.

TMS recently published the study "Creating the Next-Generation Materials Genome Initiative Workforce". The current independent and more general workforce study reinforces the MGI study findings that the foundational pillars of Data, Computation, and Experiments require key competencies in data science, modelling and simulation, and advanced experimental tools. Action plans from the MGI study include modernizing academic curricula and developing tools for continuous learning and workforce education.

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Online, links to:

Material Advantage

TMS professional development and young professionals pages

TMS 2021 Annual Meeting and DMMM4

MGI workforce development study

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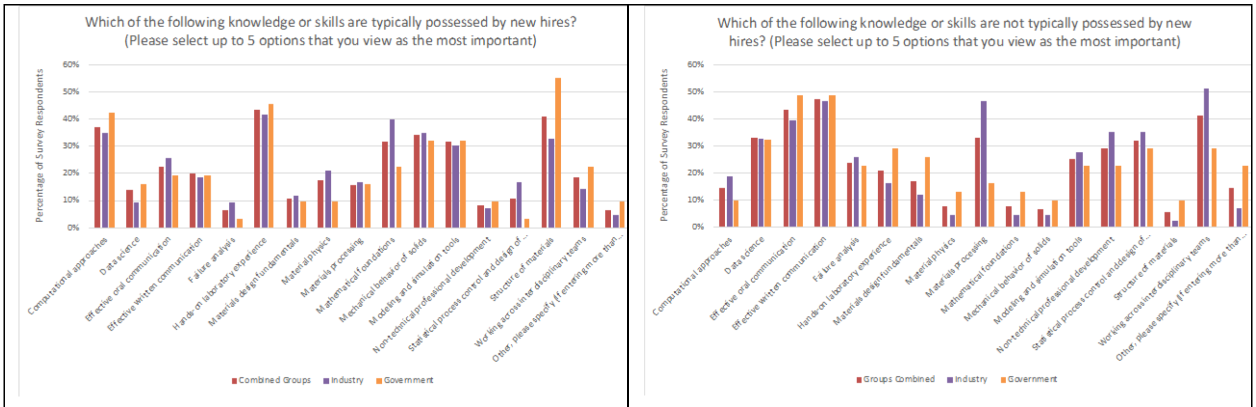
Figures and Tables:

Table 1 (100 words + 100) – Specific skills listed in the survey, of which the top 5 were selected.				
Mathematical Foundations	Materials Physics	Mechanical Behavior of Solids	Structure of Materials	Materials Design Fundamentals
Materials Processing	Statistical Process Control and Design of Experiments	Modeling and Simulation Tools	Computational Approaches	Data Science
Failure Analysis	Effective Communication	Working Across Interdisciplinary Teams		
Other (summary of responses received): (A - academia) mechanical engineering (I/G – industry/government laboratories) proposal writing, chemistry, critical thinking, awareness of fields (e.g., nuclear), programming, basic computer skills, industrial work habits, deadlines, accuracy, communication (phone v. email v. text) (RG – recent graduates) Six Sigma principles, project engineering, industry best practices				



(a) (b)

Figure 1 – Percentage of survey respondents indicating the skill sets that are (a) and are not (b) possessed by new hires.

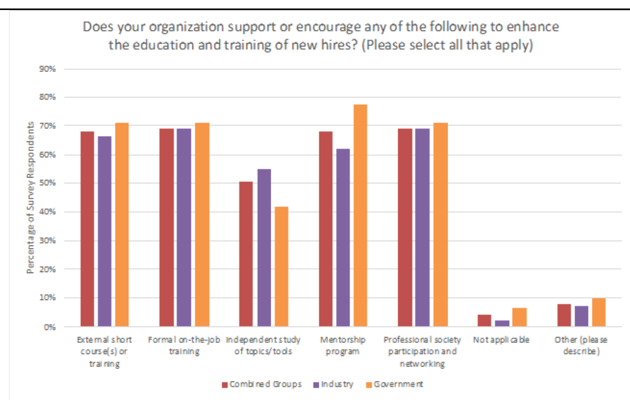
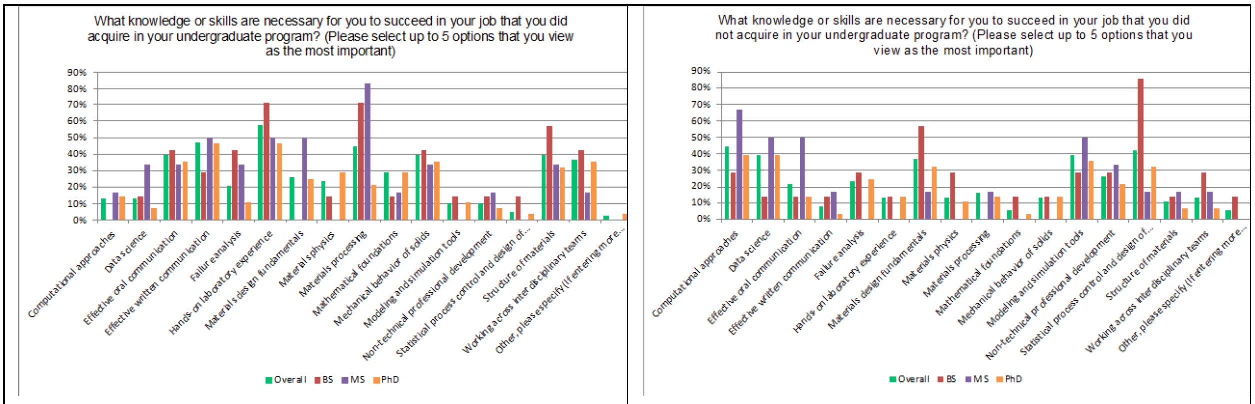


Figure 2 – Percentage of survey respondents indicating organizational support and encouragement for the indicated continuing education opportunities.



(a) (b)

Figure 3 – Percentage of new graduate survey respondents indicating the skill sets that they did (a) and did not (b) possess after graduation.

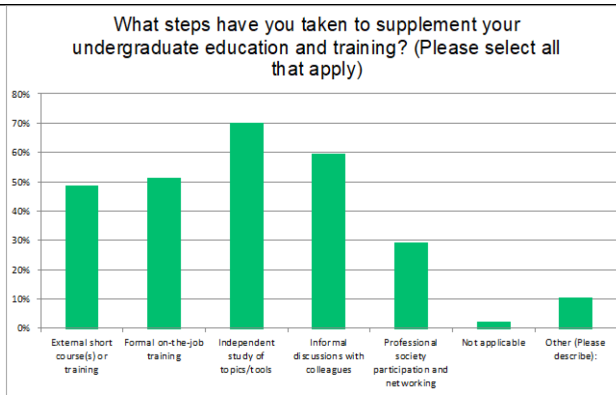


Figure 4 – Percentage of recent graduate respondents indicating they have supplemented their undergraduate education and training with the listed continuing education opportunities. The "other" category response was graduate school in all cases.

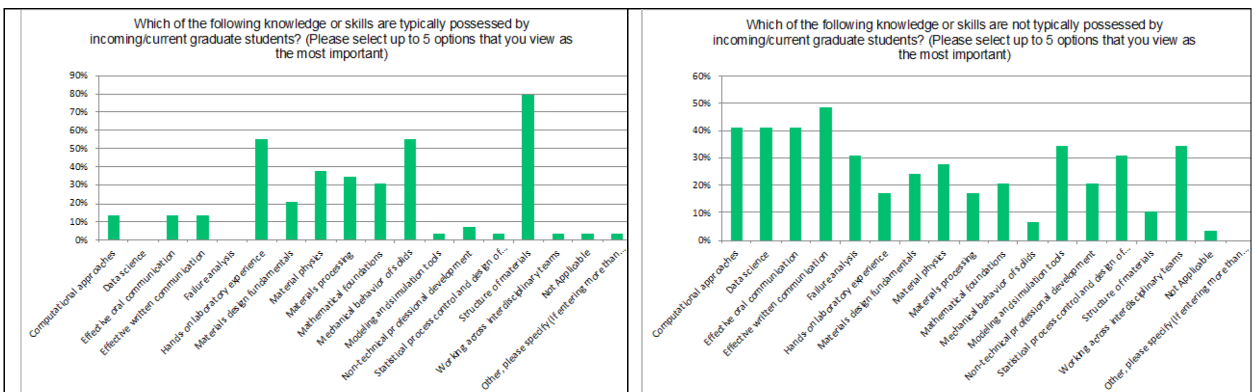
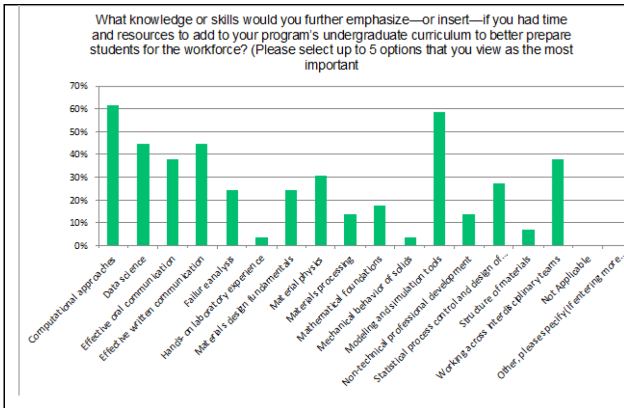


Fig 5


What knowledge or skills would you further emphasize—or insert—if you had time and resources to add to your program's undergraduate curriculum to better prepare students for the workforce? (Please select up to 5 options that you view as the most important
70%
60%
50%
40%
30%
20%
10%
0%
Computational approaches
Data science
Effective oral communication
Effective written communication
Failure analysis
Hands-on laboratory experience
Materials design fundamentals
Material physics
Materials processing
Mathematical foundations
Mechanical behavior of solids
Modeling and simulation tools
Non-technical professional development
Statistical process control and design of...
Structure of materials
Working across interdisciplinary teams
Not Applicable
Other, please specify (if entering more...

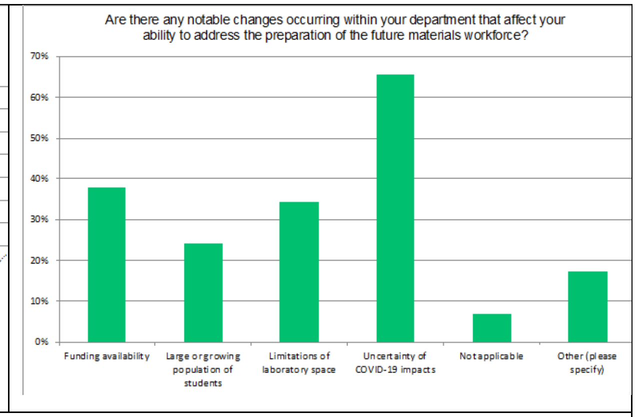

Are there any notable changes occurring within your department that affect your ability to address the preparation of the future materials workforce?
70%
60%
50%
40%
30%
20%
10%
0%
Funding availability
Large or growing population of students
Limitations of laboratory space
Uncertainty of COVID-19 impacts
Not applicable
Other (please specify)

Fig 6