Analysis of education background of faculty in materials science and engineering

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Introduction:

For over 100 years, Materials Science and Engineering (MSE) has undergone a transformation in its name, content and character to keep up with the changing needs of our society. In the late 19th century, schools of mines were prized additions to land grant colleges and universities. These institutions trained a workforce adept in the science, chemistry and extraction of minerals and ores and developed processes and instrumentation to make large-scale industrial extraction and purification of minerals possible. Applied science, particularly industrial chemistry provided further impetus to the study of processes and materials important for human society to progress. The insatiable demand for iron and steel during the early part of the 20th century gave birth to metallurgical engineering departments across the country that focused on techniques to produce steel with properties tailored to specific applications. The focus from iron-based alloys shifted to alloys based on nontraditional metals such as aluminum, titanium, tungsten, etc during the Second World War as application demanded materials to meet stringent performance criteria in ships, warplanes and communication equipment. Finally, the post Second World War era has witnessed the emergence of "non-metallic" materials including ceramics, polymers and semiconductors. These materials have positively impacted every aspect of human life and continue to improve our living standards even today.

History therefore indicates that MSE departments have always faced the challenge of adapting a curriculum that encompasses the past, present and future of materials. In this respect, MSE is more diverse, interdisciplinary and forever fickle and labile than any other engineering discipline. This fact of course helps to further the cause of MSE education while complicating it at the same time! One of the often neglected areas of policy planning and research in MSE, is trying to understand and therefore quantify, the academic background and preparedness of the faculty. After all, these faculty members strongly influence the teaching portfolio, the course design and its contents within a department. They also influence the nature and quality of research both within their own labs and as multidisciplinary, collaborative units within larger organizations. Thus, it is important for the MSE community to take stock of who the faculty is, where they come from and what kind of skill sets they bring to the department in order to meet the challenge that MSE faces with the changing needs of our society. This paper therefore, addresses this need for the first time. We take a look at the top 25 MSE schools within the United States and perform a statistical analysis of 547 faculty members in these institutions. Parameters such as undergraduate (UG) and doctoral degree specializations and institutions are analyzed. Even though no standardized database exists, we use the departmental web pages to extract this information. Some aspects of the analysis results are surprising and some results are as expected. Either way, the report draws a line in the sand for educators and administrators in MSE to look at and perhaps make more informed decisions about MSE education in this country.

Methodology:

The survey was performed amongst 25 of the nation's well known MSE departments and programs. In all, data from 547 faculty members was obtained via information on departmental or personal web pages, where published. The list of institutions and number of faculty surveyed is provided in the appendix. There is certainly a need to standardize the format and information on faculty profiles across various universities. For example, we found limited information on the year when a degree was granted or when the faculty member joined his/her current institute. This information could provide useful insights on the evolution of MSE in the last few decades and spot meaningful trends in hiring within MSE departments. Still, in many instances, no information was found on UG degrees, granting institution or year when a degree was granted.

We found that the biggest variation in data occurred in the naming convention of the formal degrees awarded to the faculty. For example, a large fraction of the faculty members were awarded PhD's in metallurgy, ceramics, polymers or MSE. For our analysis, these degrees were all 'binned' to a single category – 'MSE'. Similarly, chemical physics, applied physics, nuclear physics, astrophysics and physics were assigned the generic name 'physics'. We treated the broad field of engineering (with sub fields ranging from mechanical to electrical, etc), chemistry (chemistry, biochemistry and physical chemistry) and sciences (applied science, natural science, geology, and even mathematics) similarly as well. This made our categorical analysis simpler and without loss of information on important trends. All analysis were done on JMP® statistical discovery software.

Results:

We first look at the UG degree of faculty members in the 25 MSE departments surveyed. This is shown in **Figure 1**, left. The percentage of faculty who have an UG degree in MSE is 28.5%. However, an almost equal number of faculty have a UG in physics (26.7%) while other branches of engineering and chemistry contribute 23.3% and 18% respectively, to this list. These results are surprising and indicate that in the current MSE departments, only 1/3rd of the faculty have formal UG degrees in MSE and 3/4th have degrees either in the pure sciences or in other branches of engineering. Since the reverse trend (i.e., MSE graduates teaching in the sciences, for example) is highly unlikely, we term this scenario the "academic valving" effect.

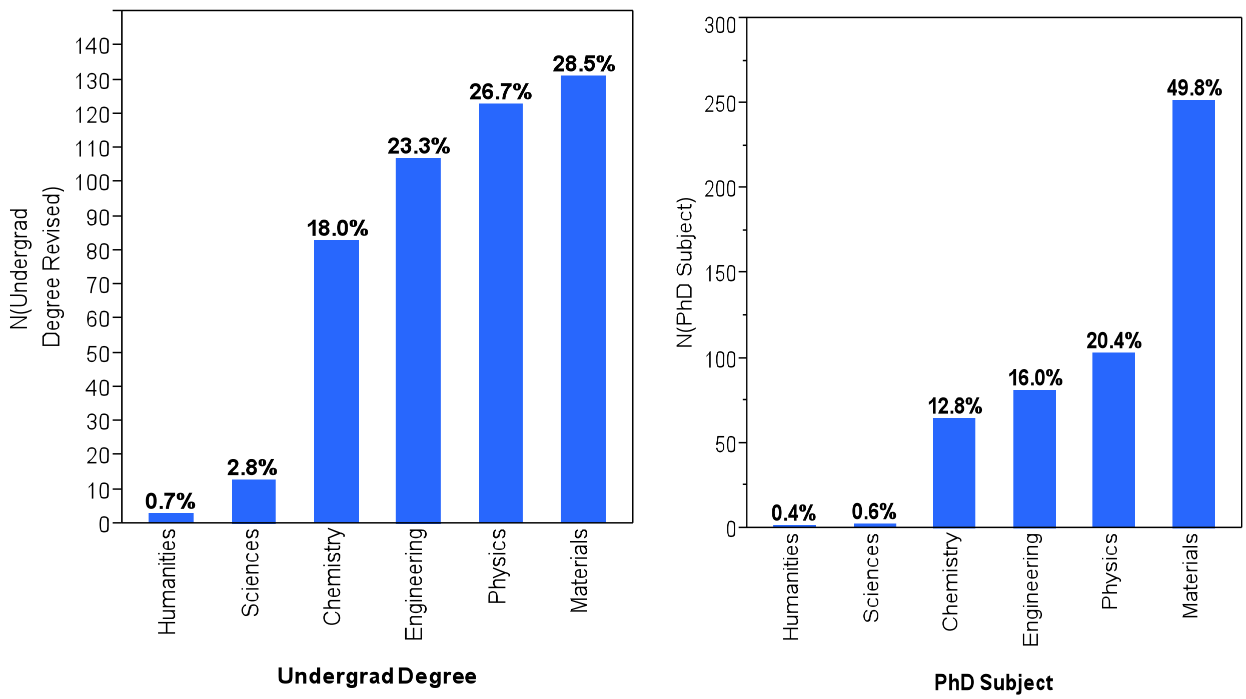

Figure 1: Left graph shows the number of undergraduate degrees in various broad disciplines of current MSE faculty across the US. Right graph shows the number of PhDs in various broad disciplines of current MSE faculty across the US.

These trends should impact UG curricula design. In particular, interesting questions about how MSE can capture the traditional, core ideas rooted in thermodynamics, phase transformations and kinetics (that are taught to traditional MSE undergraduates) and still be able to train students in subjects closely aligned to modern nanotechnology (ideas on quantum mechanics, increased understanding of the fluid state, ab-initio modeling and simulation in materials, etc.) need to be addressed. Another interpretation of these results could be for one to ask the difficult question of whether these low numbers indicate a systemic problem in MSE UG curricula which discourages or event prevents students to pursue a career in academia? This question is much harder to answer as students who opt to study MSE over, say a physics UG degree, are perhaps inclined in doing applied research or working for corporate institutions to begin with. It will certainly be instructive to conduct similar surveys in other, more traditional fields of engineering such as chemical, electrical or mechanical engineering and see whether similar trends exist in those fields or not.

When the current faculty is analyzed for their PhD degrees, the trends follow a similar pattern as above, except now a doctoral degree in MSE accounts for half of the degrees granted. This is shown in **Figure 1**, right. Physics, engineering and chemistry follow next and together account for the other half. The combined trends from Figure 1 point to an out flux of many undergraduates from physics, engineering and chemistry who chose to go to graduate school in MSE. Could this mean that a graduate curriculum in MSE is attractive and relevant to undergraduate science and engineering majors? This is an open question.

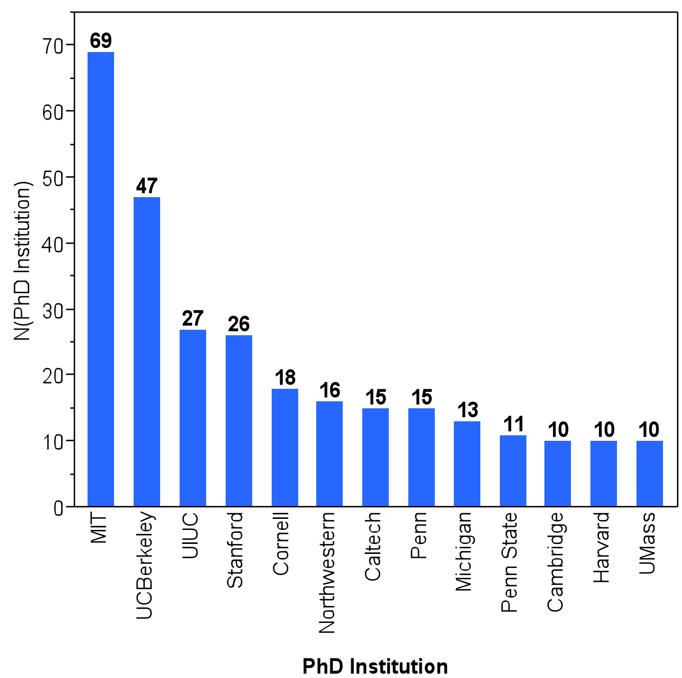

Figure 2: PhD institutions and the number of doctoral awardees who are current MSE faculty. The list has been limited for institutions that have 10 or more graduates as MSE faculty. MIT and Berkeley account for nearly 21% of the sample of 547 faculty members surveyed.

The analysis further points to the highly interdisciplinary nature of MSE research today. MSE has greatly benefitted from the fresh infusion of ideas that graduates from Science-Technology-Engineering-Mathematics (STEM) fields bring to the department. MSE research is more exciting, relevant and at the forefront of many technology innovations in our society, thanks in large part to the diverse group of extremely talented individuals who chose to enrich MSE with their professional backgrounds and experience. Again, it would be worthwhile to see what trends other branches in engineering reveal.

We now take a look at the degree granting institutions in MSE who have been successful in placing their graduates in academia. Out of a total of 547 MSE faculty surveyed, MIT and University of California, Berkeley account for ~21% of the PhDs granted and by far lead the pack. Here we show only those institutions which have contributed 10 or more faculty members to the MSE academic community (**Figure 2**). University of Illinois, Urbana-Champaign (UIUC) and Stanford follow next on this scale. Both these institutions are well known for their strong materials program. Other powerhouses in MSE such as Cornell and Northwestern also feature in this list. The University of Massachusetts with its strong Polymer Science and Engineering program has actively sent its graduates into academia as well. It is also worthwhile to note that Cambridge University is the only non-U.S. university to be in this list, having contributed 10 of their graduates to MSE departments nationwide.

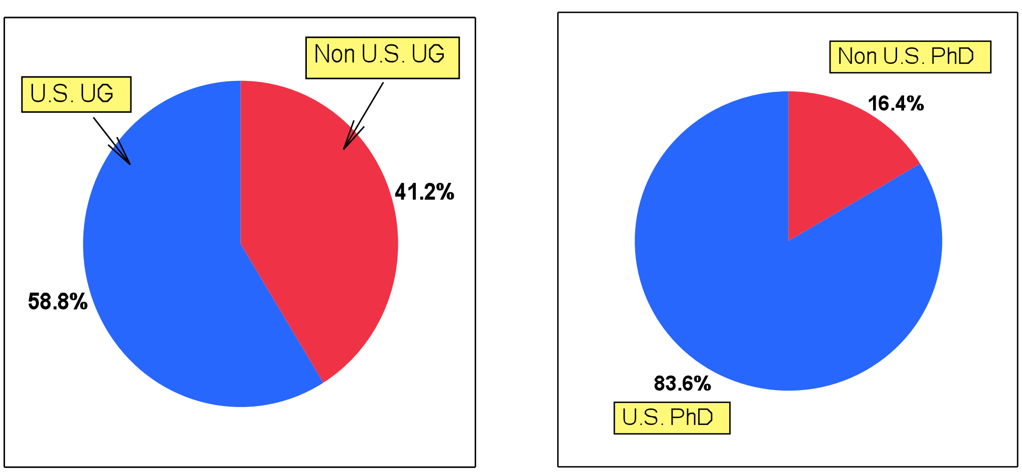

Figure 3: Left pie chart shows the % of MSE faculty with UG degrees from US based (blue) and non-US based (red) institutions. Right graph does the same analysis for doctoral degrees.

When faculty UG and PhD degrees are analyzed based on nation granting the degree, the results indicate the continued success of US higher education in attracting talent from the rest of the world. According to **Figure 3**, about 41% of the MSE faculty have their UG degree from another nation. However, this number shrinks sharply to 16% when looking at doctoral degrees. This indicates that within the sample of faculty members analyzed, 25% of foreign born MSE undergraduates come to the US to obtain their PhDs and stay back to join academia.

Next, we look at joint or affiliate appointments of MSE faculty members. From the sample studied, around 35% (190 out of 547 in total) of the faculty members had joint/affiliate appointments in other departments and schools (**Figure 4**). A total of 21.6% of the faculty were associated with the mechanical engineering department and this appeared to be the most popular association for MSE faculty members. Chemistry, chemical engineering and physics follow next. Bioengineering and related departments (biomedical, etc) have shown recent upswings in joint affiliations as well. Again, it would be instructive to see how other disciplines within engineering fare. Regardless, the data reiterates the interdisciplinary nature of MSE.

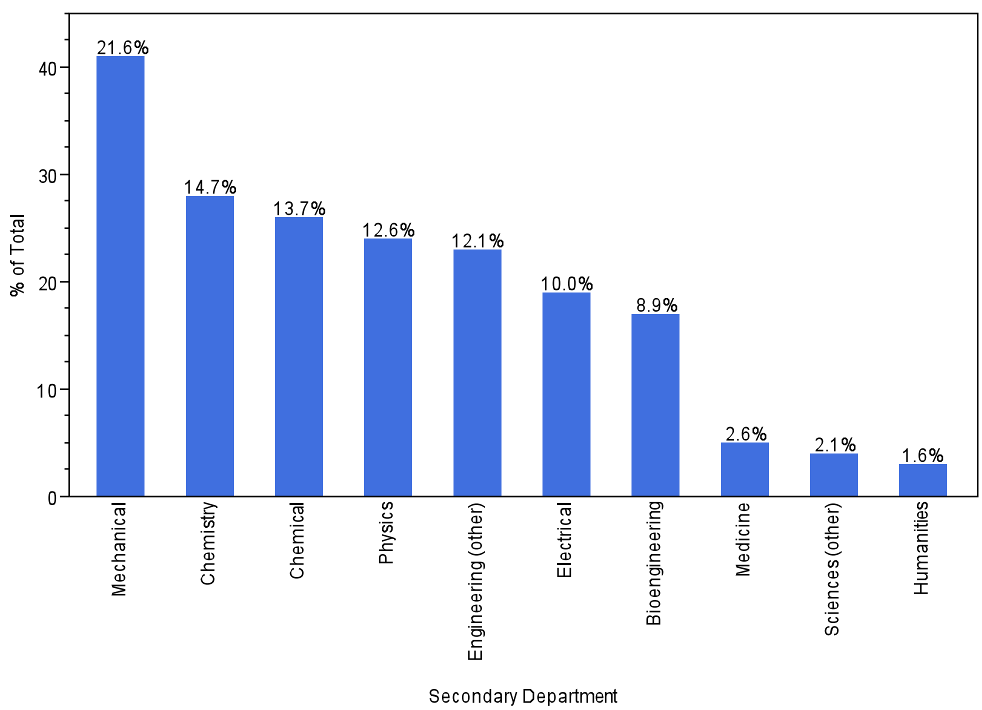

Figure 4: MSE faculty joint/affiliate appointments with other disciplines. The total number of faculty members who have such an appointment is 190 out of a total of 547.

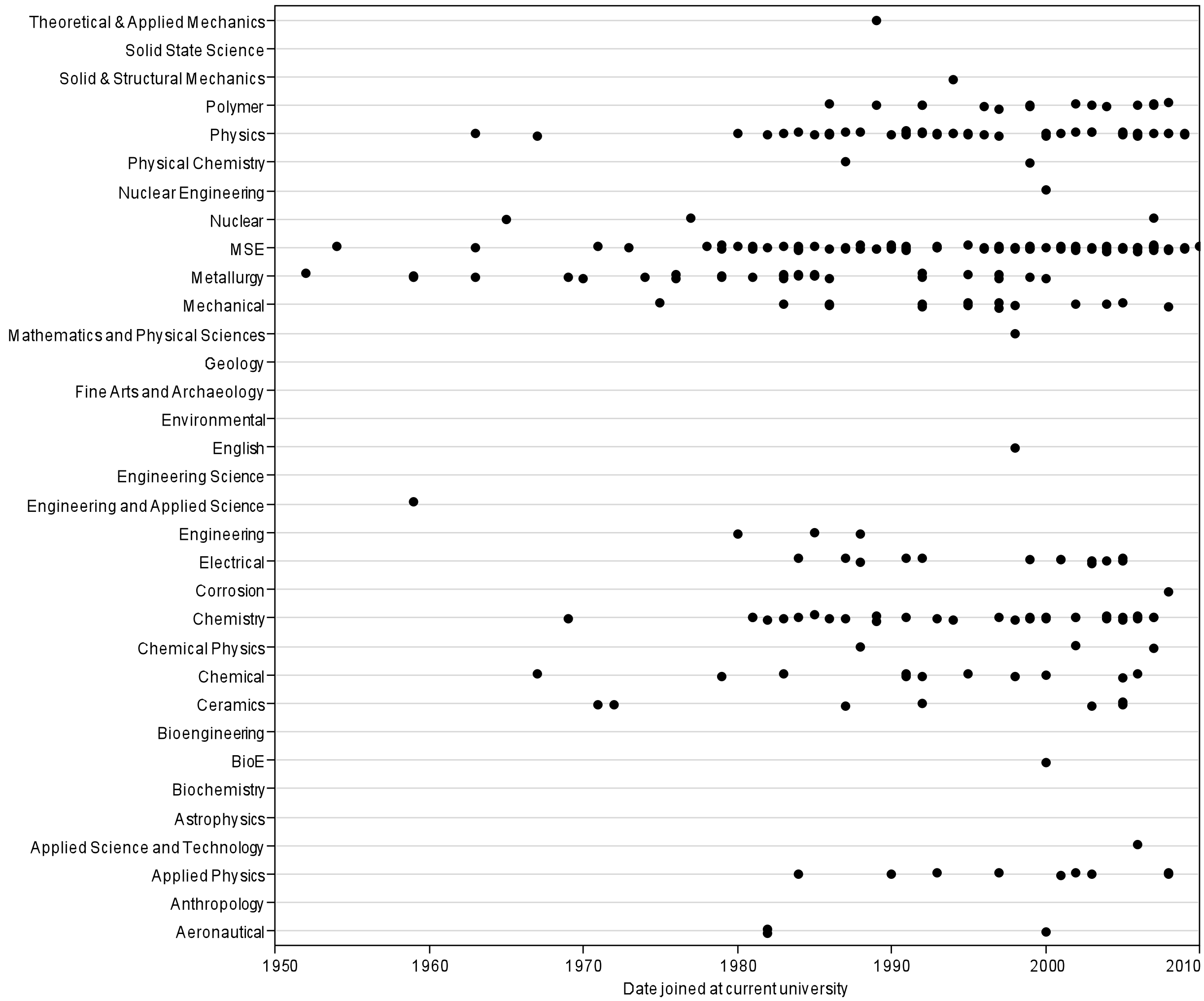

Figure 5: Time line from 1950-2010 of active faculty members and their PhD subject or fields of specialization. The 'date of joining' on the X-axis refers to the year in which the faculty member joined his/her most current position.

Finally, we look at the time line of hiring trends in MSE departments over the last 6 decades, from 1950 to 2010. This data was obtained from faculty members who still maintain active status on the departmental web pages. Obviously, many hires from the 1950-1960s have already retired and thus the reader should bear that in mind while reading the trends in **Figure 5**. The oldest hires in MSE departments come from the field of metallurgy. This hiring continued till about 2000. However, since 2000 there have been no hires in MSE departments of faculty members from that discipline. Steady hiring of MSE graduates started in the late 1970s and into the 1980s matching the time line of many departments which switched from teaching traditional metallurgical engineering courses to more MSE based curricula. This trend has continued till date. The hiring of physics and chemistry graduates started in the early 1980s and is still continuing. Polymers and electrical engineering show a similar uptake in hiring, starting from around the middle 1980s. Not surprisingly therefore, **Figure 5** reflects the six decades of historical trends in MSE as a discipline quite well.

Conclusions

In this report we have analyzed the academic backgrounds of MSE faculty members in the 25 top US universities. We find that a vast majority (75%) of the faculty have their UG degrees in diverse fields especially physics, other branches of engineering and chemistry. About half the faculty have their graduate education in physics, engineering and chemistry as well. These results indicate an 'academic valving' effect which allows researchers from other branches of STEM to enter MSE but not vice versa. At the same time, it also highlights the interdisciplinary and evolving nature of MSE – a unique situation within all branches of engineering. MIT and Berkeley graduates dominate the faculty roster. The continued supremacy of MSE and higher education in general, in the US is also reflected in this survey. We find that almost 25% of the current MSE faculty members obtain their bachelors degree in a foreign country but are retained by the US after their doctoral degree and made part of the higher education academic workforce. Mechanical engineering department leads other disciplines in the joint/affiliate appointments of MSE faculty members. The time line of hiring for MSE faculty provides a snapshot that captures the changes in MSE discipline and curricula since the last 6 decades. Such surveys should be conducted once a decade and supplemented with data from the periodic reports of NSF/NRC review panels on MSE.

Appendix

Institution Name	# of faculty scanned
Georgia Tech	43
MIT	40
Northwestern	38
UT Austin	35
Michigan	32
NCSU	29
Penn	29
UC Berkeley	28
Florida	28
Purdue	26
UCSB	26
Rensselaer	25
UIUC	24
UCLA	21
CMU	19
University of Wisconsin-Madison	19
Cal Tech	16
Cornell	16
Penn State	16
Washington	15
Arizona State	12
UMD	8
Stanford	1

The table above shows the school surveyed and the number of faculty members from each MSE department who maintained active academic and biographical data on their web pages.