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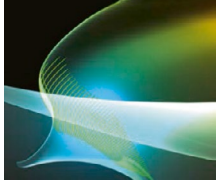

PERSPECTIVE

Materials science community support for teaching sustainability

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ABSTRACT

The materials science community has expressed a strong desire to include sustainability in the educational experience. There are opportunities to include these topics throughout the curriculum and a need to make educational resources widely available.

Materials play a key role in enabling technological and economic development. With growing need to adopt a sustainable development approach across technical fields, it is useful to review the current state of teaching sustainability pertaining to Materials Science education. Using two sets of direct interviews with a subset of Materials Research Society (MRS) members and a survey of the entire member community, we present specific observations on the perception towards sustainability, and the gaps and impediments in teaching sustainability at undergraduate and graduate levels. There is strong interest in the materials community towards incorporating sustainability into the educational experience, and opportunities for developing and disseminating a robust set of educational resources (case studies, etc.). There is also a need for developing definitions and topics that emphasize both integration of general sustainability topics as well as basic sustainability technical principles. Based on the analysis, specific recommendations were made to the MRS and the materials science community in general in order to advance sustainability education.

Introduction

There is strong interest from stakeholders throughout the materials science community (employers, faculty, and students) to learn more about sustainability. Evidence of this includes numerous examples of sustainability actions on university campuses,[1-11] and a high response and commitment in activities related to sustainability that MRS carry out. However, while there are many tangible implementations of sustainability, there are not as many formal programs or courses, especially those that have a direct materials science connection at the undergraduate and graduate level.[12]

The Educational Resources Taskforce is a group of volunteers dedicated to work to identify the need and gaps to include sustainability principles into materials science education. This Taskforce was created in July 2018 by the Focus on Sustainability Subcommittee from the Materials Research Society (MRS), as a way of expanding its efforts in this topic. We conducted this study among MRS members to assess interest in incorporating sustainability into the educational experience, identify the gaps and impediments, identify the types of resources needed, and determine what role, if any, the community thinks the MRS should play in this effort.

Discussion

- A survey of MRS members revealed that students, faculty, and employers agree to the importance of integrating sustainability into the curriculum.
- There is also a critical need to develop and disseminate educational resources.
- The MRS has the opportunity to take a leading role and becomes a model society in sustainability education.

Our study consisted of three data collection events (two interviews and a survey) used for the analysis, with insights from the earlier events guiding later events, thus continuously refining the approach. The first event held at the Spring 2019 MRS meeting conducted in-depth interviews (S19) with the goal of identifying overall trends and thoughts. A survey offered to the entire membership in October 2019 (F19) was conducted to get the broadest possible reach of the community. The information from the S19 interviews was used to guide F19 survey development. Surveys by their nature provide limited depth of response, so respondents were given the opportunity to indicate their openness for an in-depth follow-up. A subset of these respondents was contacted in July 2020 (S20) to collect their perspectives as well as answer additional in-depth questions.

There was excellent membership participation in the events, we conducted 25 interviews for S19, 419 responses for F19 survey (more than 4% response rate of the membership), and 24 S20 follow-up interviews. (As an indicator of success, a 4% response rate is considered high, the usual rate for MRS surveys is around 1%.)

All three stakeholder groups (Students, Faculty, and Employers) indicate they want more support for the development and dissemination of educational resources and better integration of sustainability into the curriculum. An educational imperative exists as indicated by a majority of Employers surveyed believe there is a competitive advantage to hiring people whose training includes sustainability. Students also recognize the importance with respect to career prospects, but also strongly believe that it is imperative to implement sustainable practices for the general well-being of the planet and humanity. Additionally, both Faculty and Students want it to be taught. There is support for integrating it throughout the curriculum with dedicated courses, course modules, and case studies. Lastly, there is also a belief that the MRS can and should consider playing a pivotal role in collecting and disseminating the educational resources and encourage new ones to be developed.

Background

The overall goals of this report were to identify if there is a need to teach sustainability and if so how to address it. Therefore, at a high level, questions center around the following:

(1) How much importance does the Materials Science community place on sustainability?
(2) What is the community's understanding of sustainability (definitions and topics)?
(3) How widespread is sustainability education and how is it taught?
(4) What are the gaps and impediments to teaching or learning about sustainability?
(5) What types of resources work and would be effective?
(6) What role might the MRS play in supporting this effort?

We asked these questions among different stakeholder groups to get a comprehensive view of the different stakeholder opinions and examined the data by regions to see if different approaches and needs would be necessary. Stakeholder groups consisted of Faculty, Students (including post-docs), and Employers. Employers included individuals from both commercial enterprises and national laboratories/government. Regions were split by continent, except for the United States which was put in its own group, and Oceania was combined with Australia (see Table 1).

Since the goals of the survey and interviews were similar, quantitative results are from the F19 survey unless otherwise noted, while qualitative results and comments are aggregated from all three events.

Table 1. Stakeholder group sample sizes for the different events.

Stakeholder Group	S19 Count	S19 Fraction	F19 Count	F19 Fraction	S20 Count	S20 Fraction
Faculty	5	20%	155	37%	18	75%
Student	14	56%	127	30%	2	8%
Employer	6	24%	37	9%	3	13%
Gov't			29	7%	1	4%
None	–	–	71	17%	–	–
Total	25	100%	419	100%	24	100%

Results

Priority

To understand if anything should be pursued with regard to educational resources, it is necessary to assess if the Materials Science community believes sustainability is important. In short, there is across-the-board belief of respondents that sustainability is important to the future of the discipline. The F19 survey showed 80% personally believe it is critically important, and another 18% rate it as important, and it is consistent among all stakeholder groups, (see Fig. 1).

Additionally, the consensus of the Employer respondents is that sustainability is important to business. This was already stated by R. Priddy, who affirms that companies adopt sustainability actions and plans, even in some cases despite of lack of regulations and laws.[13] 80% of Employers rate it as important or critical to their organization's success. As for using it in hiring decisions, about 55% of Employers believe there is an advantage for job candidates to have sustainability training, while 33% of them believe critical thinking skills and a passion for sustainability suffices. The proportion of comments from interviews corroborated these thoughts as well. Both the Student and Employer groups align on their agreement of sustainability's career importance. It is therefore important to instruct Students about sustainability and the necessary skills to assess and implement it in the workplace, during their formal education and ongoing professional development.

Interestingly, the findings show Employers view sustainability as an economic opportunity; they believe improving production efficiency, and reducing waste and pollution are the biggest opportunities, all of which align with the bottom-line issue of reducing cost (see Fig. 2). These sorts of comments imply durability to Employer interest. Respondents are from Basic Materials (75%), Energy Production (85%), Transportation (100%), and Electronics (80%), industrial sectors rated sustainability as critically important or important. The skills wanted within the different industries in new hires vary. Transportation relies most heavily on life-cycle assessment, while Energy Production and Basic Materials want to see training in sustainability principles. Electronics tends to rely on on-the-job-training. For industries that tend to be more heavily regulated, the importance of non-technical skills suggests that inclusion of economic and regulatory topics would better prepare students.

One interesting finding is that while Faculty rating of sustainability matches that of the other stakeholder groups, only 40% of Students believe that Faculty places an importance on it. This indicates a perception gap, which was not explored further during this work. Possible explanations include a lack of explicit mention on sustainability during the education experience, or a statistical anomaly such as population bias (because people who participated in this study are strongly interested in sustainability) or lack of correlation coupled with institutional variability.

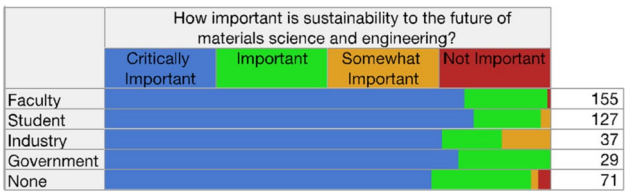

Figure 1. Overview of sustainability importance to the Materials Science community from the F19 survey. The sample size for each category is on the right.

Definition and key topics

Sustainability has been difficult to describe given its pervasive nature. For comprehension assessment, respondents were asked for their definition of sustainability and key technical topics. One question in the S19 interviews asked for the definition of sustainability. There were a variety of answers, with about 10% relying on the Brundtland definition;[14] there also was a lack of awareness

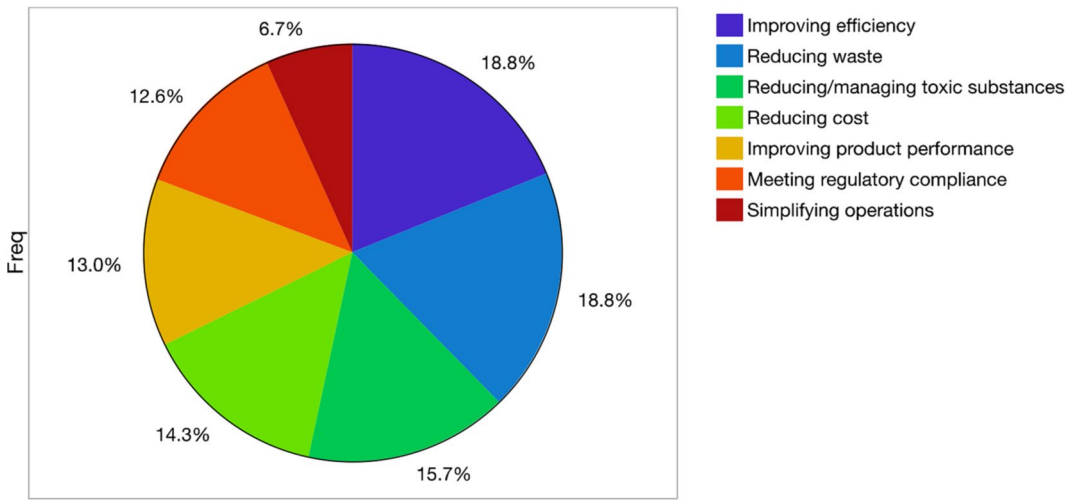

Figure 2. Employer rankings of biggest sustainability opportunities within their organization.

of the United Nations Sustainable Development Goals (UNSDG). Each of them embodied a portion of the following sustainability definition developed by the taskforce:

> Sustainability in the context of Materials Science is the study and improvement of materials, processes, and materials performance to help people meet their needs indefinitely.

The most common classes of topics given in descending order of occurrence were (1) recycling, waste or toxicity reduction, (2) new materials for sustainable applications, and (3) fabrication efficiency. Respondents were then asked to list the most important sustainability topics to them. The most popular topic was Designing Materials for Recycling and Reuse (20%), with Design for Sustainable Applications (15%), Reducing Toxic or Hazardous Substances (14%), and Improving Materials Performance (14%) in the next tier. Other topics included life-cycle assessment, and environmental remediation. The complete ranking is listed in Fig. 2.

A related question was to list the topics that are taught to undergraduates. The three most common topics taught (in decreasing order of occurrence) were as follows: Improving Materials Performance (21%), Designing for Sustainable Applications (12%), and Process efficiency (12%), Environmental Remediation (10%), and None (10%) (see Fig. 3 for the ranking of all listed topics). This shows somewhat of a mismatch between what is believed to be important (designing for recycling and reuse) and that is taught (improving materials performance). A list of individual comments related to important topics are listed in Appendix 9.1 (Fig. 4).

An attempt was made to examine the correlation between topics that Faculty said they taught with what Students believed they experienced. It is expected that ranking and correlations should have a positive relationship, which was the case for designing for sustainable applications.

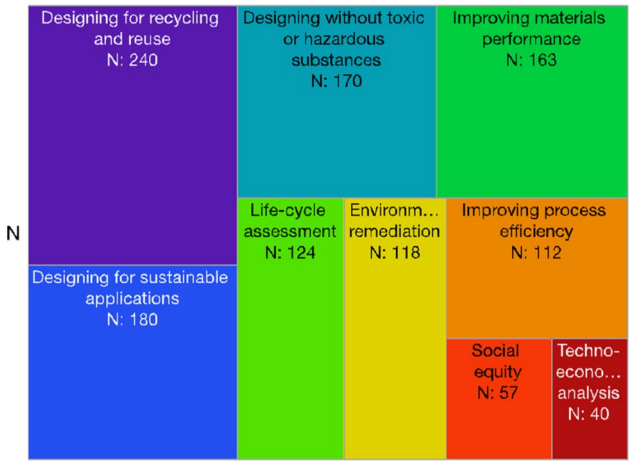

Figure 3. Treemap of most important sustainability topics of respondents from F19 survey (they could choose up to three).

Table 2. Regional differences in the fraction of Students were exposed to sustainability during their higher education experience.

Region	Exposed to sustainability
Africa	85%
Asia	74%
Europe	54%
United States	41%

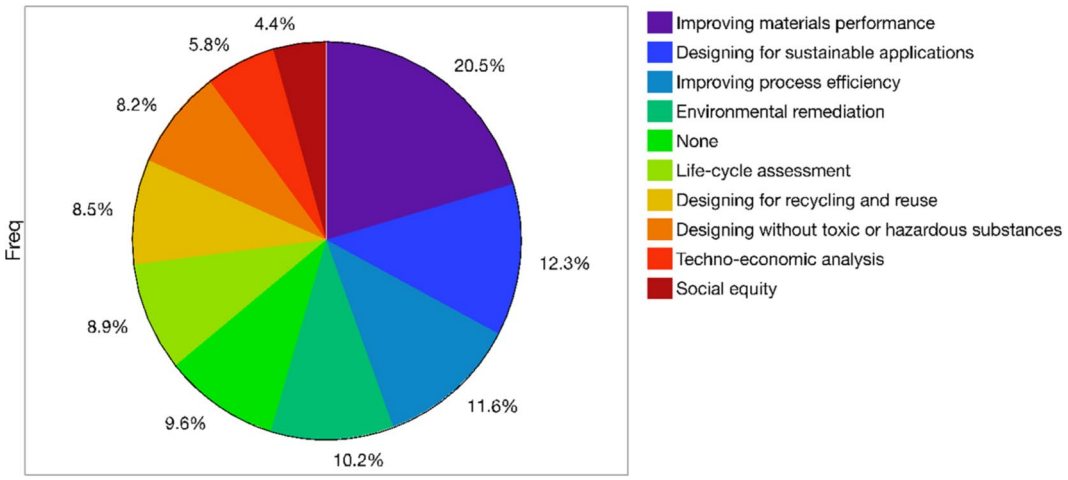

Figure 4. Sustainability topics taught to undergraduate Students.

Teaching sustainability

In the survey 61% of Students said they were first exposed to sustainability during their university experience, with the majority of them having exposure during a course. Virtually, all Faculty respondents (99%) believe that sustainability should be incorporated into the curriculum, and while 70% say that they already teach it, 94% identified a gap in how it is being incorporated. Again, there is a perception gap between Faculty and Students respondents, in that only 40% of Students said that sustainability is being taught. Additionally, 23% of Faculty replied their own department offered sustainability courses, while only 17% of Students were aware the courses were offered. Around 10% of universities offer a minor or degree with good alignment between Faculty and Student responses. Of the four regions with a minimum of 30 responses, there was a stark difference in exposure of Students to sustainability varying from 85% in Africa down to 41% in the United States, (see Table 2).

Gaps and impediments to teaching

In reviewing the S19 interviews, the Faculty stakeholder group wants to teach more about life-cycle assessments, integrate sustainability as a core concept, incorporate sustainability into more modules, and tie in social and environmental connections (e.g., regulatory, economic). This last comment speaks to the fact that many issues in sustainability have multiple solution, but it is necessary to be aware of the societal constraints and requirements to select paths that are useful, efficient, effective, and minimize unexpected detrimental outcomes. Student learning gaps indicate that they would like more of an industrial focus when discussing sustainability, and have sustainability integrated throughout the curriculum. The Employer group wants employees with a sound understanding of sustainability concepts and critical thinking skills. The clear message is that sustainability is not adequately included in the curriculum (76%); only 6% feel it is adequately covered.

Students were asked if they feel they had enough exposure to sustainability during their undergraduate education. Regionally, Asia lags the rest of the world in teaching sustainability at about 35%. Other regions vary 65% to 90%. North America and Africa have the highest percentage of dedicated courses. While North America and the United States have the lowest indication for Student satisfaction for sustainability coverage (25%), the rest of the world averages about 50%. This indicates about 20% overall satisfaction with coverage level on sustainability.

The biggest impediments that Faculty listed for teaching sustainability as a percentage of total Faculty respondents are the general lack of educational resources (21%), insufficient space in the curriculum (20%), and lack of textbooks (19%). In terms of specific resources that are lacking from a regional perspective, in Asia/Europe Faculty want more lecture notes and textbooks, while in United States/North America/South America they want case study materials and project plans, while in Africa they want software.

Summaries of individual comments include (for more detail see section "Impediments to teaching" in Appendix) the following:

1. Several Faculty mentioned that their stakeholders and administration do not find sustainability to be an important topic. Reasons believed include, lack of government support or funding, not related to the discipline, fundamentally not necessary to consider, and an already overcommitted/diluted curriculum.[15]
2. Another common Faculty response was a lack of teaching resources in general. A common refrain from Faculty in South America was a general inaccessibility of case studies, software, and data sets for training students (presumably for Life-Cycle Assessment), which is attributed to cost.

Requested educational resources

There was good alignment when it came to identifying needed resources among Faculty and Student groups. Overall survey results indicate a need for resources for active learning, such as case studies (21%), projects-based learning materials (17%), lecture notes (16%), course modules (16%), and textbooks (15%). Furthermore, they recommend integrating it throughout the curriculum (35% Faculty/31% Students), dedicated courses (23%/21%), case studies (21%/27%), and where possible have an industrial focus (19%/21%) in the resources. Other resources that had about 16% support include project-based learning materials, lecture notes, course modules, and textbooks. Comparable results were also seen in the S19 interviews. Some respondents provided recommendations on other resources including field study projects from organizations such as IEA (International Energy Agency), EIA (Energy Information Agency, US DOE), IPCC, and Deep Decarbonization Pathways Project; integrate sustainability concepts into laboratory courses and promote thesis work in sustainability. Individual Faculty responses for additional resources include the following: (1) A better coordinated plan, (2) Sources of future changing job scenario/disruptive technologies, and (3) None. In several responses, students requested that there be focus on industrially and commercially relevant examples. They voiced strong support for interactions with industry, for example, having industrial professionals talk with them about their experience with sustainability and plans for implementation. These responses are in agreement with some authors that suggest that there is a need for higher education students to have interdisciplinary training, involving social, environmental, and economic factors, and acquire critical thinking and problem-solving skills.[16,17]

Faculty were asked to give their opinion on how to incorporate sustainability into the Material Science curriculum. As shown in Fig. 5, the most common response was to integrate it throughout the curriculum (36%), followed by providing an industrial focus and offering dedicated courses. As each respondent was able to choose more than one option, we suggest that a combination of several modalities coordinated would be a good approach, especially including dedicated courses to provide depth and focus.

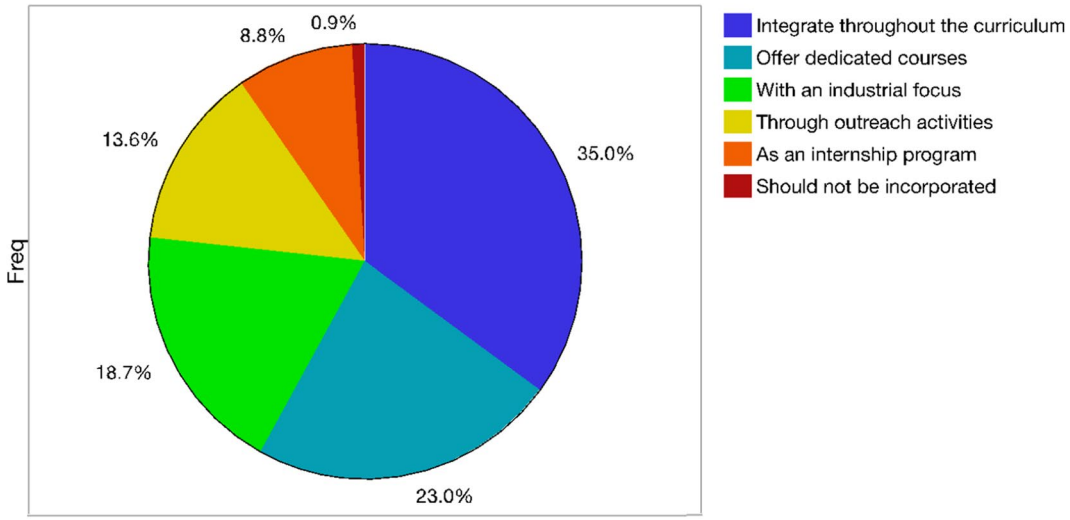

Figure 5. Faculty recommendations on how to incorporate sustainability into the Materials Science curriculum.

The MRS role

The role of the MRS is to enhance professional development of its members and advance the discipline itself, therefore it is necessary to assess what the membership may want the MRS to do to support sustainability. Therefore, we asked members if the MRS should provide support to implement sustainability and if so how (see results in Fig. 6). In the S19 interviews, 95% said the MRS should support sustainability in education, 5% said no. In the F19 survey, Faculty would like to see the MRS help facilitate access to resources (26%), offer symposia (18%) and workshops related to sustainability (18%), and help develop new resources (29%). Students and Employers roughly equally weighted the same four categories. Many expressed their admiration that the MRS is taking a leading position with regard to sustainability.

A primary purpose of the S20 interviews was to follow up with membership to gather key messages outside of the survey. About 25% of respondents said they would be willing to be contacted for further discussion, the taskforce was able to sample about 8% or respondents. As the MRS is the nexus for all materials science stakeholders, the community provided numerous recommendations with respect to how it can assist this effort. They are listed here for reference:

Professional training

1. Develop an economic argument for sustainability to attract industry.
2. Need to train engineers in frameworks outside of the technical one of their discipline (e.g., policy, regulatory compliance, etc.) to improve self-awareness of sustainability.

Education

1. Provide a method to disseminate educational resources to the community. Several members suggested a curated website from which material could be directly downloaded (preferable from the viewpoint of maintenance of live links) or refer to external links.
2. Actively foster development of educational resources.
3. Broadcast the definition of sustainability to the membership.
4. Develop a technical consensus on sustainability topics and subject matter.
5. Develop an introductory materials classes dealing with (1) sustainability applications, and (2) introduction of sustainability in Materials Science that teaches the broad definition of sustainability, including topics such as policy, and health and safety.
6. Introduce life-cycle assessment earlier and include in product design classes.
7. Practical exercises are a good teaching method.

General suggestions

1. MRS can influence public opinion and should do so; and help develop members to reach out themselves more effectively.
2. Incorporate sustainability in everything the MRS does, such as bulletins, advocacy, lobby the federal government, highlight papers, and from a practical perspective in all society operations.
3. Encourage MRS Student chapters to develop a sustainability focus.
4. Provide low-cost access to databases for life-cycle assessment especially for developing countries. There is free software but with limited data.

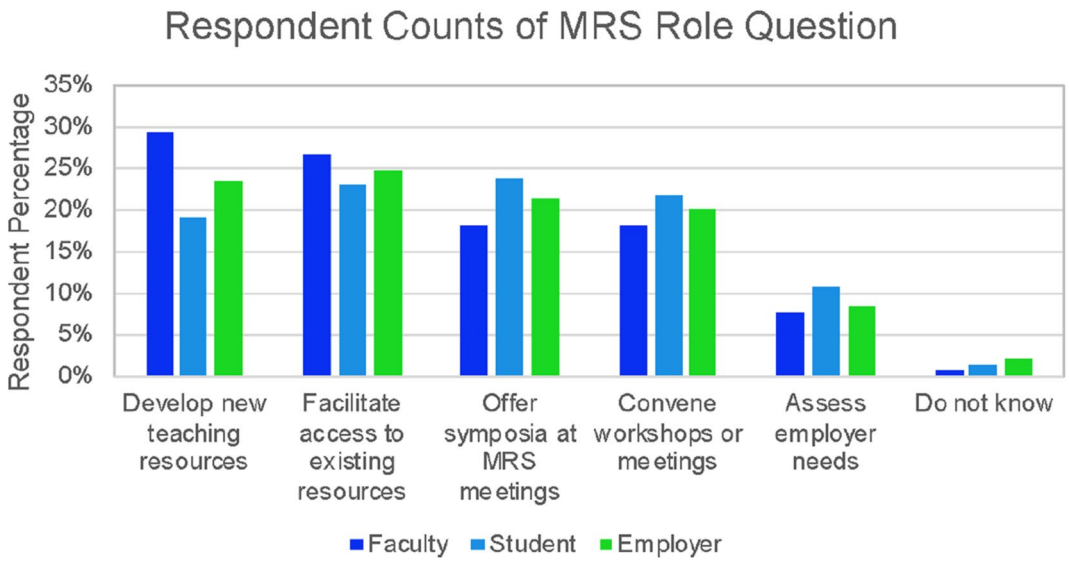

Figure 6. Comparison of recommendations for MRS by stakeholder group.

Recommendations

There is widespread support for teaching sustainability among all stakeholders within the materials science community. While some materials exist, creation and dissemination of a more complete set of materials to the academic community is required. There are several suggestions including fostering development of improved resources and enabling easier dissemination. Most importantly, this presents the MRS the opportunity to take a leading role in becoming the reference society for educating technical professionals about and promoting sustainability. We suggest that the MRS focuses on (as detailed below) (1) developing a materials science-based sustainability definition, (2) encourage educational resource development and dissemination, and 3) foster the creation of a panel to frame a curriculum. The taskforce has reviewed the input from the membership, and makes the following recommendations, separated them into those for the general materials science community and the MRS in particular:

Materials science community

The community as a whole should take up the effort to develop opportunities to teach sustainability. Opportunities include the following:

1. Develop educational resources like lecture notes, case studies, textbooks, and project plans.
2. Develop planning materials, including example course aids like course objectives and syllabi.
3. Define a set of technical topics to cover and introduce life-cycle assessment, as well as how to link into non-technical aspects such as public policy, economic, regulatory, and societal aspects.
4. Expand teaching the design of materials for recycling and reuse.
5. Develop opportunities to provide an industrial/commercial perspective in sustainability course work.

Materials research society

1. Create a definition of sustainability as it pertains to the Materials Science community.
   a. Emphasize basic sustainability principles to build common foundation, thereby facilitating coherent development across disciplines. Use UNSDG as a starting point.
2. Encourage educational resource development. Some suggestions include the following:
   a. Offer workshops and symposia related to educational methods and resources.
   b. Encourage community members to develop and share various educational resource types, such as case studies or course modules. One mechanism could be to use a challenge prize model based on stakeholder-reviewed ranking.
3. Ask the University Materials Council or the MRS's Career Advancement Committee to convene a panel for creating/assembling resources and framing a curriculum.
   a. Highlight how sustainability can mesh with existing materials science educational objectives, and where necessary create new objectives.
   b. Encourage inter-university collaboration. Some collaboration between universities already exist and have been quite successful.
4. Provide mechanisms to disseminate educational materials to the community, such as a curated website. Curation

can be achieved through stakeholder-base, volunteer members, dedicated staff review. Ideally, the MRS would provide website space for this resource.

5. Lead outreach to other professional societies, especially technical ones, to share best practices for developing and disseminating educational resources.
6. Create venues for sharing educational concepts and planning for members. Try to include input from industry and government.
7. Provide support for international faculty who want to implement sustainability in their courses or institutions:
   a. Making educational resources/curriculum available to other countries' entities responsible for curriculum development.
   b. Provide a mentoring program for faculty in developing countries.
   c. Facilitate development pairings with institutions in developing countries to develop educational resources.
8. As the Focus on Sustainability task force has advocated, encourage adding sustainability elements into technical symposia planning.
9. Raise visibility of sustainability by practicing sustainability, for example, implementation as part of meeting operations.

Summary

There is clear support from all stakeholder groups for more support for development and dissemination of educational resources and better integration into the curriculum. All stakeholders feel it is personally important, a majority of Industrial members believe there is a competitive advantage to hiring people whose training includes sustainability, a vast majority of Faculty want to ensure it is taught, and a majority of Students want to be exposed to it. There is support to integrate it throughout the curriculum with dedicated courses as well as modules. There is also a belief that educational resources should be collected and made available to the community, and where resources are lacking, new ones should be developed. The MRS has a rare opportunity to take a leading role within the materials science community to spur integration of sustainability into materials science education and development and dissemination of educational resources. More broadly, the society can lead the field of hard science disciplines with proliferation of sustainability education, perhaps the most important field of our time.

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Data availability

Reasonable requests for data will be considered.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Appendix

Topics

F19 survey topic choices

1. Designing for sustainable applications
2. Designing for recycling and reuse
3. Designing without toxic or hazardous substances
4. Improving process efficiency
5. Improving materials performance
6. Life-cycle assessment
7. Techno-economic analysis
8. Environmental remediation
9. Social equity

Individual topic responses

1. Interconnectedness
2. Sustainable energy production and storage
3. Sourcing of materials in a sustainable manner
4. Renewable energy and carbon emission-free energy
5. Recycling existing waste
6. Primary resource availability/sustainability
7. Open access to publicly funded research
8. Materials with low emissions from production
9. Materials with low CO_2 footprint
10. Manufacturing issues associated with recycling and biodegradable materials
11. Managing materials over its life cycles, understanding toxicity, including low-dose, compound effects
12. Exploiting biosynthesis to replace unsustainable manufacturing processes
13. Environmental impact of materials waste
14. Designing for energy harvesting
15. Circular economy
16. Carbon neutral energy production
17. Biologically derived materials
18. Balance of cost, emissions, and water usage. There will be tradeoffs and a framework to make decisions is needed.
19. Social equity, which is a poorly defined political construct, is not relevant.

20. Sustainability concepts are already integral to engineering disciplines.

Impediments to teaching

F19 survey impediments to teaching choices

1. No room in current curriculum
2. Low priority to Faculty
3. Not adequately covered in textbook
4. Inadequate course materials
5. Limited access to software or other practical tools
6. Not knowledgeable on the topic
7. Does not apply to my courses

Individual responses for impediments to teaching

1. Not all the courses taught adequately to apply it.
2. In some countries it is not currently seen as a fundamental topic.
3. Sustainability is and has been an integral part of engineering, so it does not need to be considered separately.
4. The definition of sustainability is hard to understand.
5. Time constraints in teaching.
6. Academic administration is interested in marquee sustainability topics (e.g., recycling) but not the complete picture such as chemical handling and waste.
7. Engineering students do not consider sustainability as a topic to include as it is not technical.

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