Teaching Environmentally Responsible Inventing:

Higher Education Environmental Landscape Research and Analysis Phase I

March 2018



Environmentally Responsible Inventing

Inventions can solve many of the biggest economic and social challenges of our time. That's why The Lemelson Foundation works to strengthen the ecosystems where inventions can take shape, grow, and flourish.

The Foundation is committed to enabling inventors to address a range of urgent social and environmental problems, and providing them with the skills, mindsets and leadership to integrate environmental responsibility throughout the invention and commercialization pathways.

Product inventions in particular can take an especially hard toll on our planet. Ensuring an invention-based business is environmentally responsible (ER) means careful consideration of all aspects of the work, including:

- Efficient use of raw materials and energy
- Reducing supply chain and liability risks
- Minimizing negative impact on the environment relative to distribution, usage scenarios and end-of-life or disposal stages



Environmentally Responsible Inventing Defined

To us, an environmentally responsible invention can come from any sector. It's not just a term used to describe breakthroughs in renewable energy or technologies for purifying unsafe water. Rather, it is a way to describe any invention that has the smallest environmental footprint possible—from the way a product is conceived and prototyped, to the materials sourced in its production, to the end of its life-cycle and how its component parts ultimately break down. Our goal is to reduce the negative environmental impacts at each step in the process.

Carol Dahl, Executive Director, The Lemelson Foundation
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Inventors need help understanding and

solving environmental problems, and we need higher education programs that can deliver these concepts and skills to them. But tools and pedagogical approaches for integrating environmental responsibility early in invention and innovation pathways are either lacking or not widely adopted in K-12 and higher education.

Research Purpose

The qualitative study, *Phase I: Environmental Landscape Research and Analysis*, sought to identify best practices in teaching environmental responsibility to inventors and innovators in higher education and to better understand constraints to integrating environmental responsibility and sustainability principles in a range of higher education invention and innovation offerings.

The project was designed to inform a second phase of work comprising conversations with additional academic stakeholders and sustainability experts and the exploration of recommendations for increasing adoption of ER that emerged from Phase I.

Researchers

In 2017, The Lemelson Foundation contracted with Jeremy Faludi, Ph.D., LEED AP BD+C, Assistant Professor, Dartmouth College and Cindy Gilbert, MS, MEd, Founder and Director of Alula Consulting, to conduct, analyze and report on a qualitative research study. This is a summary of their findings and recommendations, including excerpted data and content.



Jeremy Faludi

Jeremy Faludi, Ph.D., LEED AP BD+C, is a sustainable design strategist. He is an assistant professor at Dartmouth College and has taught green product design at Stanford, Minneapolis College of Art and Design, and elsewhere. He has contributed to six books on sustainable design, including Worldchanging: A User's Guide for the 21st Century, and co-authored the Autodesk Sustainability Workshop. He designed the first version of AskNature.org for the Biomimicry Institute, created the Whole System Mapping sustainable design method, and a bicycle he helped design appeared in the Smithsonian Cooper-Hewitt Design Museum's 2007 exhibit "Design for the Other 90%".



Cindy Gilbert

Cindy Gilbert (MS, MEd) is founder and director of Alula Consulting, which specializes in innovative sustainability education and research projects for educational institutions, non-profits and corporations. Recent clients include The Lemelson Foundation, VentureWell, PBS, Silverback Films and several universities. She has taught and led courses and workshops for thousands of people, around the world and online, in the fields of biomimicry, sustainability and biology. Until recently, Cindy was the founding director of the Sustainable Design program for 7.5 years at the Minneapolis College of Art and Design (MCAD) where she established the world's first fully online, multidisciplinary MA in Sustainable Design. Before MCAD, she served for nearly four years as the founding director of university education at the Biomimicry Institute where she developed and managed all higher education programs.

Phase | Research Objectives

The primary goal of this research was to explore leading practices and barriers for integrating ER in higher education invention and innovation activities and to start to identify potential pathways for increasing adoption. Specific objectives were:

- · Identify best practices.
- Determine best ways to introduce and maximize ER integration in invention education.
- Identify experts, what is being taught, what has been successful, what conditions are conducive to success, where are the gaps, and what are the challenges and friction points.
- Identify curricula and pedagogy in higher education that can be translated upstream to younger students.
- Create a collection of current ER innovation and entrepreneurship-focused programs being implemented around the globe in higher education.
- Develop 5-10 high-priority recommendations for next steps.

Methodology Highlights

The study included an extensive literature review and in-depth interviews with 25 interviewees representing a broad sample across several demographics. Publications were found in engineering, business and design disciplines. Interviewees included academics and subject matter experts (n=19) in academia, and alumni and inventors (n=6) in industry. Academic institutions included universities at undergraduate and graduate levels as well as community college; engineering, design and business programs, both public and private. Locations included 5 continents and 10 countries--Argentina, Canada, China, Denmark, India, Kenya, Netherlands, Sweden, United Kingdom, and the United States. Gender balance was 40% male and 60% female.

Key Findings and Best Practices for Educators

The study revealed that while there is evidence of effective curricula and instructional methods in some higher education design and engineering programs, ER coursework is not commonly required or ubiquitous in the invention education-related landscape. Nearly a decade has passed since the largest comprehensive study (Allen et al., 2008) of this field, which surveyed 1,368 administrative heads at 364 higher educational institutions teaching engineering. Such previous research, while valuable for making recommendations for best practices in teaching ER to inventors and innovators, demonstrated that the sustainability landscape has not changed as much as we might desire.

Findings in this section have been organized in three categories: curriculum, delivery methods, and administration and leadership. In each section you will find a summary of consistent themes that emerged in both the literature review and interview responses, as well as recommendations that emerged specifically related to those themes or the category more broadly (i.e. curriculum, delivery methods, administration and leadership).

These summaries are followed by graphs showing the order of the most frequently mentioned topics in the interviews. A discussion of the top most frequently mentioned topics, reasons for positive and negative mentions, and illustrative quotes follows the graphs.

CURRICULUM: Findings and Recommendations

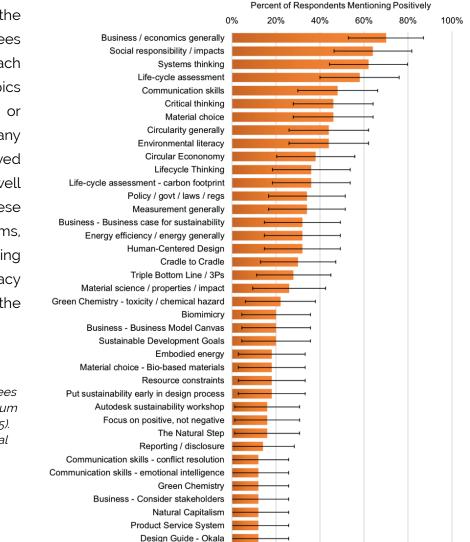
- According to interviewees, there were no "silver bullet" curricular strategies, any must-have or must-do ER activities, concepts, or tools to integrate into curricula in higher education. However, the topics most often mentioned and should be considered core were:
 - o Business and economic considerations
 - o Social responsibility / social impacts
 - o Systems thinking
 - o Environmental impact measurements and metrics (especially Life Cycle Assessment).
- Other high-priority topics include material choice, critical thinking, communication skills (both for teamwork and to be change agents), energy effectiveness, and circularity of material flows.

- Context-specific topics to be considered include environmental literacy, green chemistry, human-centered design, and others.
- Because ER invention and innovation are inherently multidisciplinary, no one student will be trained in all possible technical skills or concepts, and training in any of several different areas can enable ER invention.
- Curriculum should be flexible and allow educators room for topics specific to their field or the project at hand.

Most Frequently Positively Mentioned Curriculum Topics

Figure shows the 1 percentage of interviewees positively mentioning each curricular topic; only topics mentioned three times or more are included. Many curricular topics received negative comments as well as praise; some of these comments were criticisms. others bemoaning were the lack or inadequacy of current teaching of the topics.

Figure 1. Percent of interviewees positively mentioning curriculum topics (for all interviews, n=25). Error bars show 95% binomial confidence intervals.



| Curricular Content | Reasons for Positive Mentions and | Reasons for Negative Mentions and |
|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| (most mentioned) | Illustrative Positive Quotes | Illustrative Negative Quotes |
| Business/Economics | Practical necessity Aid entrepreneurship Business has power Positive business models Broaden scope "Viable generally means financially-viable That's the bottom line that at the end of the day, is the determining factor." "Business was probably going to be the most significant contributor to any sustainability effort on the planet, since they were simultaneously, probably the biggest contributors to unsustainable behavior." "It gives them a new perspective on this issue and helps them see, Wow, I could create a business that does this and stick it into this system and I understand now how the effects would spin out." "We make them think about other issues of sustainability. What about the people that can't afford your product but could really, really use it? How do you design a business model that enables you to generate enough revenue to stay in business, to provide this thing to the people who really need it, even if they can't pay for it?" "We need more innovations in economics and financing than we do in science and engineering to solve this problem." "How do you transition an existing unsustainable business model to a more sustainable one." | Business-as-usual fights sustainability' Not taught well Lack of business tools for entrepreneurs "If I could only defend it from a design perspective, my decisions would be trumped or pushed aside, largely by business decisions." "When you're creating a business model and you layer on this element of needing to also be sustainable and taking to account environmental impact, your bottom line is impacted. It just, it gets a lot harder to design when you have to take into account not only your financial sustainability. And so we had a real challenge with only using the business model canvas to do that." "Neo-classical economics, which is still what's being taught in most schools, is what got us in this mess, to some extent." "I see business as usual as being like the big fear, or the big barrier in the sense that we really need to look at the way we teach design, because we do not give the students the skills." "All of the tools that I've used in the past are generally meant for businesses that exist already_there aren't a lot of tools that exist for people who are developing something from scratch." "Note: this is not to say that teaching business is a problem, but rather that status-quo business practices reject approaches that add cost without adding commensurate financially-measurable value. |

Table I: Most Frequently Mentioned Curricular Topics and Reasons

| Curricular Content (most mentioned) | Reasons for Positive Mentions and Illustrative Positive Quotes | Reasons for Negative Mentions and Illustrative Negative Quotes |
|---------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Social Responsibility/ Impacts 64% mentioning positively 16% mentioning negatively | Ethical necessity Inspiration / motivation Aid real-life application Systemic integration Understand complexity of problem "It's really important they have an understanding of both the social system and the environmental system on which we rely, and to realize that we are completely nested within them, and that every action we have has an impact and that we receive resources from both of those systems particularly in the early design phase." "INot considering it] ends you up in a drill hole if you constantly only try to bite off a small chunk without having that full systems perspective first, I think you'll end up creating more harm." "Those projects are very inspiring because people relate to other people and people relate to helping other people." "I've done a project focused on low income populations. That could be anywhere as long as there's somebody on the team who has some direct, or has had some direct physical contact, or at least social contact with the group that they're talking about." | Often neglected Difficult to quantify Arrogant to decide what others need "I make a big point out of trying to make it clear that it's inappropriate for us to think that we can just step in to another part of the world, understand what their values are, and what they need, and tell them what to do. It's arrogant." "I want to push on the social side here again because I think they're lacking that They don't really see that, and I think that's a common critique of environmental work." "It's much too complex for my undergraduate students to get a grip on, for a one-day exercise." |
| Systems Thinking 62% mentioning positively 10% mentioning negatively | Broaden scope Encourages critical thinking Systemic integration Prioritize Sell ideas Understand complexity of problem "We can't look at all of these things in isolation, in silos. We have to understand they're all interconnected." "We have them analyzing complex systemsto start to understand that the problems of the world are really complexand systems thinking gives a framework for how to approach them in the most intelligent and informed manner I've encountered." | • Missing in most engineering and design |

Table I (continued): Most Frequently Mentioned Curricular Topics and Reasons

| Curricular Content (most mentioned) | Reasons for Positive Mentions and Illustrative Positive Quotes | Reasons for Negative Mentions and Illustrative Negative Quotes |
|---------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Life Cycle Assessment 58% mentioning positively 12% mentioning negatively | Compare options Set targets Monitor progress Prioritize Broaden scope Understand complexity of problem "We set targets as a company in areas such as water, energy, carbon, waste, all the impact areas on the environment and then we monitor and help the company execute against them. And we flag to executives when resources are needed, we flag to executives where we're off track." "If we are finding a hotspot in our company, we need to measure that impact, just to know the startup, where you stand now, and how to propose progressive change in order to minimize that impact." "You can't just look at, 'Well, what's the carbon footprint?'You have to look at a broader set of metrics at the 15 or 20 in a traditional life cycle assessment." "If you look at the lifecycle assessment of materials made from renewable feedstocks versus petroleum feedstocksthis is a great way to show students that everything that's bio is not | Difficult Time-consuming Too inaccurate Encourage incrementalism "IEducators] find it overwhelmingly complex for them to manage half of the students are overwhelmed by the methodology, and some of them feel overwhelmed by just dealing with the spreadsheets." "So much of this stuff is much, much more complicated than it looks, and the data is terrible." "We're all going to pat ourselves on the back for decreasing our carbon footprint by 8%." |
| | necessarily better for the environment." | |

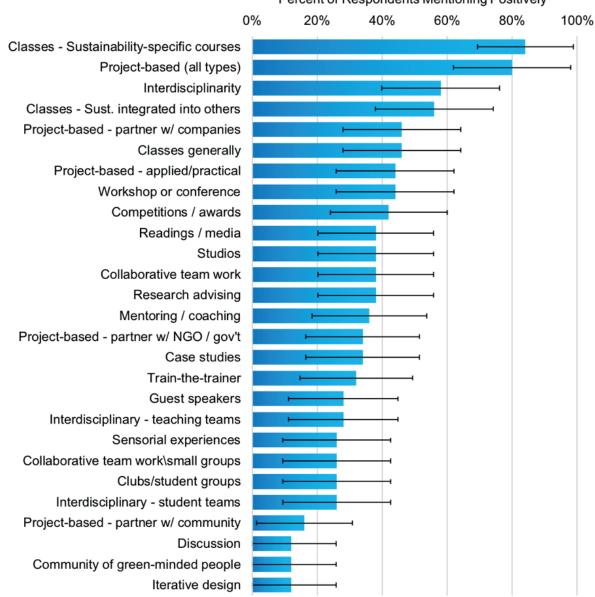
Table I (continued): Most Frequently Mentioned Curricular Topics and Reasons

DELIVERY METHODS: Findings and Recommendations

Similar to what was found in previous literature, the interviewees here reported preferring hands-on interdisciplinary teaching methods, and reported teaching either courses focused on ER engineering, design, or business, or reported integrating ER material into existing courses.

- A large majority of respondents valued sustainability-specific courses, though so many respondents valued integration into other courses that there was not a statistically significant difference. However, rather than choosing between a few marginalized sustainability classes and diluted integration into general classes, respondents were enthusiastic about full integration of sustainability throughout all classes to the point of being deeply ingrained into all curricula and the institution's mission.
- Project-based classes, especially ones partnering with companies, NGOs, government agencies, or local communities on real-world products or programs, were overwhelmingly valued in both literature and interviews. They were said to teach real-life skills, drive systemic integration of sustainability, build soft skills for teamwork, and even to help sell sustainability to companies or to school administration.
- Selling sustainability to companies and administrators is vital, because designers and engineers are often held back by business managers who do not see profit in sustainable invention or innovation, and lack of perceived value in industry causes lack of perceived value in academia. Many companies do value sustainability, but academic-industry partnerships are rare due to logistical hurdles and lack of connections between schools and interested companies or other organizations.
- Interdisciplinarity was valued on projects, both for student teams and teaching teams.
- Other highly-valued delivery methods included competitions and awards, studio experiences, research advising, mentoring and coaching, readings and other media (e.g., videos), and case studies.

Most Frequently Positively Mentioned Delivery Methods



Percent of Respondents Mentioning Positively

Figure 2. Percent of interviewees positively mentioning delivery methods (for all interviews, n=25). Error bars show 95% binomial confidence intervals.

Figure 2 shows that over 80% favored sustainability-specific classes, but the large error bars mean that this is not statistically significantly valued more often than integrating sustainability into other "normal" classes. This suggests that there are pros and cons to each approach, and that determining the appropriate path may depend on institution- or faculty-specific factors. Project-based learning was also valued by 80% of respondents, most often when partnering with companies to innovate real products, but also when partnering with NGOs, local communities, or governments. Many respondents also mentioned valuing projects without partnerships, including student-led projects. Interdisciplinarity was mentioned positively by almost 60% of interviewees; this included both interdisciplinary teaching teams and student teams.

| Delivery Methods | Reasons for Positive Mentions and | Reasons for Negative Mentions and |
|----------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| (most mentioned) | Illustrative Positive Quotes | Illustrative Negative Quotes |
| Sustainability-specific Courses 84% mentioning positively 20% mentioning negatively | Focus on key sustainability topics & mindsets "You're able to then fold the core sustainability principles into the classroom from the beginning, that's ideal." "It makes a big difference, because they really have this opportunity to go into detail and also somehow try to understand the complexity of the concepts they are developing." "Our entire course is all about getting students to think about business models plus thinking about environmental and social needs, and/or risks and benefits of that model." | Specialized classes can be marginalized "Students typically go through a four-year program and then they probably have one master class with an expert for a day, on what sustainable design is, but it's not embedded in the curriculum. Whereas, if it could be embedded in the curriculum and they are learning different aspects of it in the first year, in the second year, in the third year, in the fourth year, progressively, they get a much more ingrained way of approaching design in a more sustainable mannerit's essential for our own survival, so something as important and critical as that should be reinforced at every stage of an undergraduate program, at every stage of a design practice." "If you make it a full course elective or make it its own minor, there's also the possibility that people are going to self-select to the extent that people don't sign up for it because they don't know what it is." |

Table 2: Most Frequently Mentioned Delivery Methods and Reasons

| Delivery Methods | Reasons for Positive Mentions and | Reasons for Negative Mentions and |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| (most mentioned) | Illustrative Positive Quotes | Illustrative Negative Quotes |
| Project-based learning (both student-led and especially partnering with companies, local communities, NGOs, or government) 80% mentioning positively 16% mentioning negatively | Deep learning Real-life applicability Systemic integration Building teamwork skills Selling sustainability to companies and/ or administration "Project work is totally important, otherwise students just don't learn." "Only when you try to apply your knowledge, that's where the learning comes." "How you really give engineers or inventors context that gives them an amazing capacity to actually respond to some of these issues is to hitch into the organizations, the entities that have gotten the big attention." "Applied project based learning from the get-go, where they really very effectively thread ecological principles and sustainable designs into the curriculum from the beginning" "It's always good to get more training in that and knowing one's self and knowing one's triggers and knowing how that arises, and then being able to recognize that in other people. We have some serious work to do in the next decade or two, and I find that the interpersonal team dynamics get in the way more often than they should." | Logistical challenges Disconnect between teaching and research objectives "It's really difficult to combine how do you assess the projects? There are different assessment criteria in different institutions and it somehow needs to be fair for everyone." "As a researcher, I would never think to do that because I don't look at applications." |

Table 2 (continued): Most Frequently Mentioned Delivery Methods and Reasons

| Delivery Methods | Reasons for Positive Mentions and | Reasons for Negative Mentions and |
|------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|
| (most mentioned) | Illustrative Positive Quotes | Illustrative Negative Quotes |
| Interdisciplinarity 58% mentioning positively 4% mentioning negatively | Systemic integration Broaden scope / perspectives Teamwork skills "[Interdisciplinary teaching teams] are talking about it in their discipline's language it completely resonates with the things that I talk about, but it's spoken in a different language that the students hear differently." "We teach by teams, so I'm working with people who know stuff I don't know, like about accounting." "[In interdisciplinary student teams] you were somehow forced to collaborate with others that had different ways of thinking, and then knew different things. It was very much about somehow appreciating all the different kinds of knowledge that we had in our group." "Really figuring out how linterdisciplinary student teams] can be working with people who just are trained really differently." "It was one of the first in the country that had these interdisciplinary design studios. My observation is that I think that it's a tremendous education for the engineers who are taught almost nothing about practical design of anything." | |

Table 2 (continued): Most Frequently Mentioned Delivery Methods and Reasons

ADMINISTRATION AND LEADERSHIP: Findings and Recommendations

- Most sustainability programs start with a faculty member (or small group) creating an
 elective course, then proving its worth to administration, so the administration supports
 the initiative by providing funding, or making the course required, or integrating some of its
 content into other required courses.
- The best administrative leadership partners with faculty to deeply integrate sustainability into all aspects of education—electives and required courses, research, even campus operations. Most literature and interviewees described faculty-led efforts that acquired administration support through grants, coordination, other resources, and institutional esteem.
- Signatory commitments, such as Talloires Declaration (ULSF, 1990) and the Green Chemistry Commitment (Beyond Benign, 2017), and sustainability scorecards, such as the Sustainability Tracking, Assessment and Rating System by the Association for the Advancement of Sustainability in Higher Education (STARS, AASHE, 2017), are some of the approaches that can advance administrative commitment and integration.
- Unsurprisingly, grants, funding, and other resources were valued, and the lack of funding or other resources was a frequent complaint, cited by some as a primary reason why ER was not being integrated into academic programming. Further, lack of funding was cited by inventors for hindering sustainability-focused invention.
- Classes were most often offered as electives versus being required; this was not due to preference, but because of how the academic system works.
- Successful integration of ER into higher education will need to overcome four main barriers frequently mentioned by interviewees: conservative or status quo faculty, lack of faculty knowledge, academic hoops, and lack of demand from most businesses. Approaches for overcoming these barriers could include:
- o Groups of faculty working together also strengthen the integration of sustainability, as can student demand.
- o Sustainability curriculum mandates from state or local governments, or accreditation boards, could also serve to greatly align administrative resources and incentives, as they have in some European universities. However, such top-down measures could also backfire and cause more resistance, so feasibility studies should be performed before the foundation lobbies for such mandates.

- o Support for faculty training and development can help overcome barriers of status quo faculty and faculty knowledge.
- o Partnerships with companies can help overcome the barrier of perceived lack of business demand; if such partnerships are financially sponsored, they of course also overcome the barrier of lacking funding, as well as academic hoops and status-quo faculty.
- o Attempts to reduce academic hoop barriers by convincing tenure review boards to change tenure criteria are likely not to work as effectively in the short-term as professional development and external partnerships with industry.

Most Frequently Positively Mentioned Administrative/Leadership Integration Topics

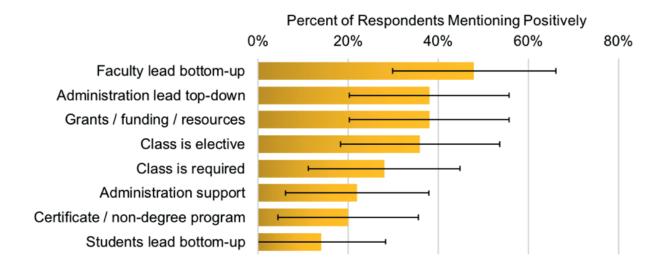


Figure 3. Percent of interviewees positively mentioning administration / leadership technique (for all interviews, n=25). Error bars show 95% binomial confidence intervals.

Figure 3 shows roughly half of respondents valuing bottom-up faculty-led efforts, but top-down administration-led efforts were within errors bars. Elective classes are more common than required classes, but not necessarily more valued. Many administrative techniques received negative comments as well as praise; some of these comments were criticisms, others were bemoaning the lack or inadequacy of current implementation.

| Administrative / Leadership (most mentioned) | Reasons for Positive Mentions and Illustrative Positive Quotes | Reasons for Negative Mentions and Illustrative Negative Quotes |
|---------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Faculty-Led Bottom-Up 48% mentioning positively 14% mentioning negatively | Ethical necessity Systemic integration (if working together) Working with like-minded people Inspiration "It should be how everything is taught, and I don't understand why people think that this is still a specialty. It's mind-boggling." "Sustainability is a moral and ethical imperative. So to me, it is a no-brainer. There is moral and ethical and there's obviously a commercial viability. If we train our inventors to have this, we will be more successful. Society will benefit economically but also from safety and better products." "To find like-minded people in other faculties and in other departments, and to set up a network of people who want the same thing" "We all were changed, our perspectives were changed because we learned from each other, about each other's disciplines." "There are faculty who play like kind of a sustainability cheerleader role, if you will, myself included. There's maybe four of us who are kind of pushing more for it, but that's it." | Lack of power (requires administrative support) Lack of systemic integration Lack of faculty understanding Lack of faculty agreement "It's going to be lots of work. So, if you want to make a change, think five to ten years for things to move." "The first two conditions you need is having top management buy-in, so at least they will support you and then get a course in, a compulsory course in the curriculum in some way or another. And then from there on, start building." "In every university in the world, there is one or two faculty members in chemistry that get it. And they want to do invention, they want to do sustainability. But if they retire, if they go to another university, it's gone. It's not systemic, it's to the individual." "The disadvantage is that nothing's centralized, and so getting resources is extraordinarily difficult" "In practice there are just not enough teachers who understand the topic" |

Table 3: Most Frequently Mentioned Administrative/Leadership Topics and Reasons

| Administrative / Leadership (most mentioned) | Reasons for Positive Mentions and Illustrative Positive Quotes | Reasons for Negative Mentions and Illustrative Negative Quotes |
|------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Administration-Led Top-Down 38% mentioning positively 14% mentioning negatively | Effective to start initiatives Government support valued "There were some kind of commitment signed by university presidents and I think our president was involved in that and signed that. And so, at that point, people started to take it seriously" "And then in a university, we've got the Green Chemistry Commitment asking for systemic curriculum change that is lasting." "In Denmarkl It's a right-wing government that's not very interested in environmental issues. Even them, they still have a big push forward towards circular economy. It's not something that's sort of progressive, or unique that we're working with that. It's basically just required, even just the government will have told educators that they need to work with this." | May backfire where faculty and administration at odds Administrative turnover makes support uncertain Lack of understanding or lack of rooted commitment lead to ineffective policies "Having leadership ask for it may not actually be a good idea, because there's so much tension between faculty and leadership." "We've got a lot of churn in the upper administration. So, things are constantly changing and I'm constantly trying to have to repackage what I'm doing to get approval and that takes time away from the doing of the thing. A little bit is okay because it keeps us on our toes, but it's becoming more and more difficult to do it." "From the institution side, there is a push for sustainability; there isn't necessarily a full understanding of it. It's like one of those buzzwords that gets put into a lot of course descriptors but it's not actually checked if the depth is there It seems like saying the word is often enough for the institution." |

Table 3 (continued): Most Frequently Mentioned Administrative/Leadership Topics and Reasons

| Administrative / Leadership (most mentioned) | Reasons for Positive Mentions and Illustrative Positive Quotes | Reasons for Negative Mentions and Illustrative Negative Quotes |
|------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Grants / Funding / Resources 38% mentioning positively 6% mentioning negatively | Enables inventors to launch companies Enables teaching, research, buying equipment, etc. "We did apply for and received a grant, which is how we got started in this category." "There wasn't funding on a venture side and we weren't yet technically mature enough to get more sophisticated, say, NSF-style federal grants. And so [a small grant] really bridged a gap for us." "We just got, I think, a half a billion dollars from Phil and Penny Knight to develop something called the Knight campus for accelerating the impact of scientific innovations. And the idea there is to sort of take everything that we've learned from these different kinds of experiments and create a separate unit." | Funders restrict innovation Lack of funding "You must convince the grant reviewers that this isn't that big of a deal, that 23 other people are doing [variations] Don't worry, this is safe. There's going to be a lot of papers published. This is not going to fail." Isee later discussion on lack of funding for further quotes] |

Table 3 (continued): Most Frequently Mentioned Administrative/Leadership Topics and Reasons

Most Frequently Mentioned Barriers to Administrative/Leadership Integration

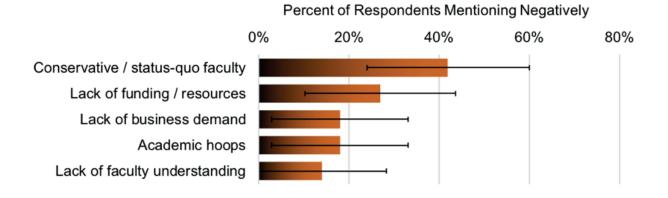


Figure 4. Percent of interviewees negatively mentioning administration / leadership barriers (for all interviews, n=25). Error bars show 95% binomial confidence intervals.

Figure 4 shows that common barriers are lack of funding, conservative / status quo faculty (any faculty not motivated to integrate sustainability into teaching), lack of business demand, and lack of their own knowledge or expertise in sustainability.

To successfully integrate ER into higher education, the barriers mentioned by interviewees are as important to consider as the leadership practices. The four barriers mentioned frequently were conservative or status quo faculty, lack of faculty knowledge, academic hoops, and lack of business demand.

| Administrative / Leadership Barriers (most mentioned) | Reasons for Negative Mentions and Illustrative Quotes |
|-------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Conservative / Status-Quo Faculty | Obstruct integration |
| 4% mentioning positively 42% mentioning | "You've got so many things that are being suggested. You can't do them all. So how do you come up with a decision of who wins? And so doing nothing, it at least escapes that God awful problem of, well, what are we going to do?" |
| negatively | "The mirror effect: I didn't do it, so why should my students?" |
| | "The older staff usually is very skeptical about the need to incorporate sustainability." |
| | "Someone working on things like organizations or someone who is working on operations, they developed their own curriculum maybe 20 years ago, and it was much more challenging to work with them, to suggest ways of changing it and bringing it up to date." |

Table 4: Most Frequently Mentioned Administrative/Leadership Barriers and Reasons

| Administrative / Leadership Barriers (most mentioned) | Reasons for Negative Mentions and Illustrative Quotes |
|-------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lack of Funding 0% mentioning | Cannot work without money Funding sources stifle innovation |
| positively 27% mentioning negatively | "We don't have enough funds; people make that argument all the time about sustainability, right? Like, you can worry about that stuff when you have more money, right?" |
| negalively | "Unfortunately nobody wishes to finance working on saving the world anymore. These are dark times." |
| | "Because of the financial constraints, there's less incentive to do off-label experimental kinds of courses, and I don't know that if I had proposed this course today if it would get approved." |
| | "I never had any grants, I had never had any funding for this. And I don't think I ever would've gotten them, because it's too different." |
| | "For you to get a grant from the Federal government you must convince the grant reviewers that this isn't that big of a deal this is not going to fail. And the only way that you can convince people that something's not going to fail is if you point to plenty of other people who are doing things that are almost the same. Now by the very definition, that is not innovative." |
| Lack of Business Demand | Barrier to educationBarrier in the market |
| 4% mentioning positively | "Companies don't look at it as a real issue, so it's not a real issue for us either" |
| 18% mentioning negatively | "[Students] may know that there's a difference between different kinds of cotton depending on where it's grown and so on, but they don't have a ruling power in order to actually make the difference. Because it's usually not their position in the companies or the organizations they take part of." |
| Academic hoops | Extra effort without recognition "Publish or perish" excludes other projects |
| 4% mentioning positively 18% mentioning negatively | "And it was a heavy lift for most of them 'cause they don't get credit in their department for doing these kinds of things." |
| πεγαιινειγ | "[It] has no relationship to how many papers you're gonna publish next year, it doesn't even fall on the radar screen of being important. And we need to change that." |
| | "If instead of publishing papers you're solving problems for society, all of a sudden whether it's sustainable or not really does matter. And so, what I feel the breakdown and the reason that academic research is not serving society, is because the inventions in academia are fundamentally not sustainable because they don't have to be to publish a paper. And we have no criteria to assess it. And so we need to find a way to get that in." |

Table 4 (continued): Most Frequently Mentioned Administrative/Leadership Barriers and Reasons

| Administrative / Leadership Barriers (most mentioned) Reasons for Negative Mentions and Illustrative Quotes | |
|-------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lack of Faculty Understanding | Lose face if students know more than them Lack expertise to develop classes |
| 6% mentioning positively 14% mentioning negatively | "Often they're afraid to include it in curriculum because they're afraid of the questions that the students will ask them, because the students are often more knowledgeable than the teachers." |
| negalively | "Because no one has ever had this training, how do you create something in a curriculum if no one's ever had classes? Who's going to be the first to teach the class if no one else has? And changing the curriculum and getting something new in is a very difficult process." |

Table 4 (continued): Most Frequently Mentioned Administrative/Leadership Barriers and Reasons

Leading Examples

A handful of examples were provided by respondents of leading institutions and programs that either deeply integrate ER into their academic programming, or are large schools with such extensive ER offerings that even without deep integration they provide top-notch education for ER in invention and innovation.

| | Institution / Program | Outstanding Practices |
|-----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|
| Schools | Presidio Graduate School (USA) | Deep integration of ER into entire institution; founded expressly to be a green business school. |
| | Blekinge Institute of Technology (BTH, Sweden), Strategic Sustainable Devel- opment program & MA in Strategic Leadership towards Sustainability | Originator of The Natural Step. Integration of ER into graduate engineering program & leadership program. |
| | Copenhagen School of Design and Tec hnology (KEA, Denmark), Material Design Lab | Integration of ER into design program, supported by state mandates. |
| | Olin College (USA) | Integration of ER into all undergraduate engineering curriculum. |
| | Delft University of Technology (TU Delft; Netherlands), Design for Sustainability group | Largest sustainable product design program in the world; grants PhDs in the area. |
| | Minneapolis College of Art and Design (USA), MA in Sustainable Design Pro- gram | Deep integration of ER into program; founded expressly to be a green design graduate program. Entirely online. |
| | Arizona State University (USA), Global Institute of Sustainability and Innovation- Space | Integration of ER into graduate design program; offer masters in biomimicry. |
| | University of Exeter (United Kingdom), The Exeter MBA | Deep integration of ER into graduate business program. |
| | Srishti Institute of Art, Design and Technology (India), Frugal Design Lab | Deep integration of social sustainability into design program; offer PhD in design for sustainable development. |
| | University of Oregon (USA), Green Chemistry program | Deep integration of ER into chemistry program. |
| Non-school content creators | Beyond Benign, Green Chemistry Curriculum | Curriculum for ER in chemistry. |
| | IDSA, Okala Practitioner | Curriculum for ER in product design. |
| | Biomimicry Institute, AskNature.org | Resource for innovative ER in design and engineering. |
| | Autodesk, the Autodesk Sustainability Workshop | Curriculum for ER in architectural engineering, mechanical engineering, and product design. |
| | Cradle to Cradle Products Innovation Institute, C2C certification online training | Curriculum for ER in product design. |
| Prominent contests | Dutch Postcode Lottery, Green Challenge | World's largest sustainable entrepreneurship contest; €500,000 prize. |
| | Buckminster Fuller Institute, Fuller Challenge | \$100,000 prize for sustainable entrepreneurship, particularly stressing systems thinking. |
| | Cleantech Open Challenge | Sustainable entrepreneurship contest at two scales: US national and regional versions. |
| | Biomimicry Institute, Biomimicry Global Design Challenge | \$100,000 prize for sustainable design. |
| | Cradle to Cradle Products Innovation Institute, C2C Product Design Challenge (design competition) | \$5,000 prize for sustainable design. |

Top Recommendations

Below are high-priority recommendations derived from the above results that are intended to inform the exploration of possibilities for Phase II of the Higher Education Environmental Landscape Research and Analysis project. Phase II will more deeply explore these recommendations, including feasibility, priority of recommendations and potential partners.

Invest in faculty by supporting their development and education. This could overcome the barriers of status quo faculty and lack of faculty understanding. Some possibilities for this include:

- Faculty workshops and trainings
- Curriculum sharing
- Curriculum development
- Academic awards / recognition

Foster external partnerships between schools and companies, NGOs, or government, especially partnerships to provide students with real-world ER project experiences. This could overcome the barriers of perceived lack of demand for ER in industry, academic hoops, and potentially lack of funding. Some possibilities for this include:

- Programs to foster project-based learning partnerships one-by-one for selected faculty
- An online platform for interested parties to meet each other for projectbased learning partnerships
- Programs to foster mentorship
- Exploring feasibility of increasing government or accreditation requirements for sustainability in curriculum

About The Lemelson Foundation

The Lemelson Foundation uses the power of invention to improve lives by inspiring and enabling the next generation of inventors and invention-based enterprises to catalyze a stronger U.S. economy, generate positive impact, and address the needs of the poor in developing countries. Established by prolific independent U.S. inventor Jerome Lemelson and his wife Dorothy in the early 1990's, to date the Foundation has committed more than \$210 million in grants in support of its mission.

Recognizing the complex challenges faced around the globe, the Foundation supports an ecosystem to address problems that are worth solving - not just problems that can be solved. This emphasis on impact inventing targets inventors and inventions that have positive social impact, are environmentally responsible and can become financially self-sustaining products and enterprises. Through the work of our grantees, programs drive adoption of Invention Education in K-12 and higher education settings and foster strong entrepreneurship ecosystems in the both the U.S. and developing countries.

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