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Educating for Sustainability as the Antidote to Global Crises:

It's More Important and Easier Than You Might Think

by Madoc Sheehan, Susan Nesbit, Edmond P. Byrne,
Nadja C. Kunz, Steven Conrad, and Katherine R. O'Brien



STEM (science, technology, engineering, and math) graduates are well placed to become the sustainability champions and practitioners the world urgently needs, if their educators burnish them with the sustainability-aligned knowledge, tools, and skills necessary for them to achieve their full potential. There are simple and effective ways educators can enhance their teaching and start the journey toward creating graduates with sustainability-aligned competencies. Complexity knowledge, innovative decision-making, creativity, critical thinking, ethics and values, systems thinking, and transdisciplinary teamwork are all important characteristics of an undergraduate sustainability in STEM education. Simply put, these skills make our STEM graduates more employable. Horizontal and vertical integration of sustainability competencies into university STEM education is widely recognized as the most effective approach, but requires educators to overcome commonly perceived barriers to teaching sustainability. Here we offer practical steps and useful resources to overcome these barriers, and enable educators to embed sustainability in their own STEM courses, degree programs, and teaching practice.

Current and recent global crises (encompassing climate change, environmental degradation, and biodiversity loss; economic inequalities and authoritarianism; pandemics and antibiotic resistance) are



Student engineer assembling robotic arm with computer in technology workshop.

symptoms of a global polycrisis of unsustainable development.¹ The polycrisis continues unabated and highlights the urgent need for society to transition to sustainable systems of production and consumption, in order to meet safe and just limits to resource extraction. Given the leadership roles that STEM graduates play in shaping society and helping to address global challenges, there is a moral and ethical imperative for university programs to provide the critical sustainability knowledge, skills, and values (i.e., competencies) to deliver this transition.² Unfortunately, most university-level STEM curricula are not yet effectively delivering sustainability competencies, thereby generating graduates

who perpetuate unsustainable practices.^{3,4} This article seeks to address this critical need for STEM curricula change and has three objectives aimed at supporting and motivating STEM educators to teach sustainability:

1. Identify sustainability as the dominant *context* within STEM education, and the need for STEM graduates to bring well-developed sustainability competencies into the workplace.
2. Help educators to develop sustainability-in-STEM knowledge and to identify sustainability aligned competencies.
3. Offer examples of the knowledge, tools and classroom activities that may be useful to STEM educators who are motivated to include sustainability in their courses.

Rapid technological development, driven in part by the efforts of university-educated STEM professionals over the past 50 years, has lifted billions of people out of poverty, but it has also damaged the environmental systems on which healthy and equitable societies and economies depend.^{5,6} For example, through its catastrophic impacts on ecosystems and societies, the climate emergency demands urgent action.⁷ Such urgency is supported by overwhelming evidence of more frequent and severe climate impacts,⁸ with impacts increasingly becoming a part



of our own (and our students') lived experience. Yet society and economies remain steadfast in their fossil fuel dependence and global carbon emissions continue to rise. On reflection, our collective failure to rise to the occasion reflects poorly on higher education providers. Contextual models of development espoused in higher education have traditionally interpreted sustainability as a specialization, or an afterthought, and environment and society have been seen as secondary to short-term economic imperatives. Such models should be revised to better serve the public's interest.

While it is not our only significant challenge, anthropogenic climate change illustrates the complex and multidisciplinary nature of sustainability issues, with solutions requiring collaboration across disciplines. Such challenges often require transdisciplinary teams to be innovative, creative, and to think critically.⁹ Reforms to meet such need are already evident in university research,

where sustainability science is emerging as a transformative model, informed by values and ethics and underpinned by the questioning of previously dominant norms and assumptions.¹⁰ In addition, the higher education sector's emphasis on research *impact* highlights the importance of values and interdisciplinary thinking. In both public and private sectors, strict disciplinary specialization in graduates is no longer deemed adequate to meet workplace needs.¹¹ Sustainability-aligned skills also enhance graduate employability, as they are necessary skills for industry to deal with growing demands to deliver on ESG (environmental social and governance) commitments. Sustainability-aligned knowledge, values and tools taught across STEM programs are critical to confronting and managing an increasingly complex world.

It is well established that production and consumption patterns need to change, for example, from so-called linear to more circular processes.¹² Yet the mechanisms by which this transformation will take

place remain unclear, and embedding sustainability knowledge within STEM curricula can, understandably, be daunting for educators. Here we offer simple steps to initiating curricular change, and we encourage STEM educators to use this commentary to begin their personal journey to incorporate sustainability competencies into their teaching practice.

The first step is to recognize, accept, and embrace an understanding that delivering more sustainable pathways involves solving wicked problems, each without unique solutions, and that cannot be solved by traditional technical approaches alone.¹³ The next step is to draw inspiration from research and build on the dissemination of our own research product to our colleagues. For example, it is now standard practice to begin papers and presentations by describing how our research contributes to improved sustainability and how such research is of benefit to society. We recommend integrating relevant sustainability-aligned research into your teaching



Water sample analysis.

practices and using sustainability-aligned research as a personal and professional development tool to broaden your personal understanding of sustainability. Such understanding will naturally influence graduate education, but teaching sustainability into undergraduate curricula is of even greater import, given the large numbers of STEM graduates entering the workplace.

In addition to using your own experience and sustainability-aligned research examples, we also recommend that STEM teachers look to professional accreditation guidelines for assistance in defining competencies and curriculum needs related to sustainability. For example, in some STEM undergraduate programs, such as chemical engineering, curricular change has been reinforced through professional accreditation requirements, which are demanding sustainability knowledge in increasing depth.¹⁴ Although there are some excellent examples of engineering programs changing via the mechanism of accreditation push (see Table 1 for examples of case studies describing



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Golden carpenter bee.

effective curriculum reforms), the sporadic nature of such reforms remains insufficient for the scale of STEM education transformation required. Responsibility must also fall on individual teachers and the teams of concerned

academics we create, encourage, and nurture, to drive the necessary reforms.

At the core of sustainability knowledge lie values, ethics, and appreciating that today's sustainability challenges are invariably multifaceted, ill-structured, value-

Table 1. Common Perceived Barriers to Teaching Sustainability in STEM Courses, and How to Overcome Them

I'm not an expert on sustainability ... No one is an expert, and authentic self-assessment is valuable. Find someone passionate about sustainability who is happy to mentor you.
My course is not about sustainability, and it's already full ... Teaching sustainability is not necessarily about adding content, but framing current content in a sustainability context, e.g., link to SDGs, sustainability competencies, discussion of the economic, environmental, and societal impacts.
Shouldn't a sustainability expert teach a sustainability course? ... Rather than compartmentalize sustainability as a separate discipline or topic in a single course, sustainability knowledge and values are reinforced if embedded in array of courses by different instructors.
Different definitions of sustainability are to be expected but I don't want to confuse the students ... Sustainability is a wicked problem: It is contested, poorly defined, inextricably linked to other problems. Teaching this explicitly prepares students to face other complex open-ended problems.
I'm already teaching sustainability, so how can I encourage my colleagues to also be interested? ... Meeting together and sharing ideas can empower many of our colleagues to teach sustainability in their courses. Seek and use feedback from students and employers about new curricula to encourage other academics to have a try.
Shouldn't this be led by the institution/profession/someone else? ... A more sustainable world starts with each and every one of us, leading by example. Yes, institutional leaders have a role to play, but wicked problems need to be tackled on multiple fronts and your leadership in teaching sustainability could be the driver of change needed to move your institution.
My colleagues have a different approach to sustainability ... There are different perspectives on how sustainability should be taught (e.g., as an imperative for all professionals, or as a consideration in decision-making); it's valuable for students to be exposed to these different perspectives.



laden, contested, and highly complex and contextual, and they lack definite solutions. They involve conflicting norms and high degrees of uncertainty, are inherently ambiguous, and often they involve political and ethical considerations. Such complex problems relevant to STEM practices include those relating to resource extraction and allocation, pollution prevention, climate change, and biodiversity loss. For example, consider the conflicts between the social and environmental impacts of critical minerals extraction and processing, and the need for such materials to help reduce carbon emissions. There are no obvious solutions to such “wicked” problems, which typically involve economic, environmental, and social trade-offs. The use of educational competencies, in this case sustainability-aligned program-level competencies, is a valuable tool to help learners think through and manage such problems. This also helps educators to define and structure the required learning and assessments. A systematic review of the sustainability education literature reveals four recurring competencies. Sustainability education trains students to:

- Develop knowledge of sustainability, including definitions and frameworks, understanding grand challenges and identifying potential solutions, and becoming aware of social norms, impacts, future scenarios, and new solutions.
- Address complex problems by using systems thinking and incorporating interactions between economic, environmental, and social systems.
- Work in interdisciplinary groups and think strategically and critically to first define and then achieve sustainability goals.



- Continually develop self-knowledge, empathy, and understanding, and strive to become exemplars of sustainability.

These competencies apply to all disciplines, and, given the resources and diversity of students within the academy, they are well suited to teaching and learning in a university setting. So, what does incorporating these sustainability competencies into a STEM teaching practice look like? How does one begin?

Well-taught sustainability competencies require the educator to consider (and integrate into their teaching) three core paradigms (economic, environmental, and social), with appropriate pedagogies: project-based learning; case studies and real-world examples; role-play; and interdisciplinary teamwork, for example. Instead of new bolt-on sustainability courses, the literature advocates for horizontal and vertical integration or embedding of sustainability curricula, which

involves significant changes to a degree program, and results in what is termed “education for sustainability.”^{15,16} In this type of reform process, educators collaborate to ensure that sustainability curricula are embedded or integrated throughout an existing degree program, across a variety of subjects, thereby affecting all courses and making all educators responsible for embedding sustainability.

In this approach, sustainability becomes the context or theme for all learning and decision making.¹⁴ Sustainability and sustainable technology become the examples or lens through which we teach theory and practice, and continual assessment of outcomes, designs, and technologies, against the three core paradigms becomes an important part of students developing their critical thinking and judgment capabilities. Sustainability examples become a tool by which educators place theory into a real-world context. When comprehensively embedded, such an approach leads to students developing a systemic and

holistic view of sustainability, enabling them to link sustainability with more traditional technical content, facilitating creativity and innovation, and opening up opportunities for multidisciplinary collaboration.¹⁶

To begin the necessary changes in teaching STEM courses, it is helpful to consider and address the multiple barriers to teaching sustainability, consult and learn from resources, then take initial steps. Table 1 offers considerations on how to address selected barriers. This combines observations sourced from sustainability curriculum literature as well as the direct experiences of the commentary team: experiences gained over more than five decades of collective effort to reform curriculum for sustainability.

Table 2 includes a selection of resources that can assist teachers to better understand sustainability applications and to learn more about sustainability competencies and characteristics, and we have provided examples that help develop sustainability

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Table 2. Resources to Help Educators Make Positive Changes in Their Subjects and Programs

Finding inspiration and hope: Sustainability solutions.	• Plastics: https://theoceancleanup.com. • Valuing natural assets: https://mnai.ca. • Mitigating risk: https://resilientcitiesnetwork.org. • Energy and poverty: https://www.honnoldfoundation.org/news. • Water and health: https://www.reseaucmi.org.
Building knowledge: Sustainability definitions/goals.	• UN Sustainable Development Goals: https://sdgs.un.org/goals. • Some sustainability definitions: https://betterfuturefactory.com/insights/definition-sustainability. • Adaption and action on anthropogenically induced climate change: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf. • Biodiversity goals: https://ipbes.net/sites/default/files/inline/files/ipbes_global_assessment_report_summary_for_policymakers.pdf.
Teaching new methods: Case studies and teaching examples.	• Looking to nature for solutions: https://biomimicry.org. • Socioenvironmental challenges: https://www.sesync.org/resources/learn-teach-socio-environmental-topics. • Circular economy case studies: https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/examples. • Life-cycle thinking: https://www.lifecycleinitiative.org/starting-life-cycle-thinking/life-cycle-approaches/social-lca. • Design for sustainability: https://venturewell.org/tools_for_design/introduction.
Defining the learning required: Sustainability competencies and educational frameworks.	• Key competencies in sustainability: a reference framework for academic program development.¹⁷ • Connecting competences and pedagogical approaches for sustainable development in higher education: a literature review and framework proposal.⁴ • Engineering education and the development of competencies for sustainability.¹⁸ • A framework for teaching socioenvironmental problem-solving.¹⁹ • Introduction of life cycle assessment and sustainability concepts in chemical engineering curricula.²⁰ • Review of competencies, pedagogies and sustainability frameworks.²¹
Broadening out the reforms: New courses and models for embedding sustainability.	• New course in civil engineering: https://blogs.ubc.ca/environmentalstewardshipandcivilengineering. • Sustainable development at the core of undergraduate engineering curriculum reform – a new introductory course.²² • Embedding sustainability into chemical engineering programs: Designing sustainability curricula: A case following chemical engineering curriculum.²³

knowledge around curriculum design. While not a definitive review, these resources will be helpful to both beginners and curriculum experts hoping to make positive steps toward change. Once barriers and resources have been considered, we suggest three steps to initiate and incorporate sustainability into your personal teaching practice:

1. Acknowledge that sustainability is an ambiguous complex problem, with contradictions and trade-offs. The challenges are always changing. While this may sound daunting, it can be used as an opportunity to connect with students and engage with their interest in the topic, explicitly

acknowledging that students and educators alike are always learning in a space without defined solutions. Talking with your colleagues about sustainability and how it relates to teaching is an important way to build community and develop great ideas, and helps us avoid feeling isolated.

Teaching Examples

- The bio-economy and biomimicry show promise for shifting society toward more sustainable production. How can we manage exploring and commercialising the medical and industrial potential of new species, with protecting DNA heritage, diverse ecological communities, and respect for indigenous culture and knowledge?
- Developing low-cost solar and wind energy developments can place pressure on our natural and protected areas and negatively impact on local communities. How do we manage ecosystem and societal risks associated with carbon emissions, against the risks associated with new green energy developments?
- Green ammonia is used to make fertilizer and is produced using renewable energy and electrolysis of water. What are the life-cycle environmental and social impacts associated with green ammonia production and how do they compare to traditional ammonia manufacturing methods? What are the important sustainability considerations in using green ammonia to reduce global emissions?
- Reducing emissions by separating carbon dioxide from combustion gases and storing it underground poses substantial social, economic, and technical challenges. Are such technologies feasible? What is the legal framework that surrounds the use of such technologies and what are the social implications for impacted communities?

Additional Resources

Inspiration from Donella Meadows, a leader in promoting sustainability and encouraging us to imagine a better world.	https://donellameadows.org/donella-meadows-legacy/envisioning-a-sustainable-world/
Life-cycle thinking is an important tool in sustainability. Here's some background with examples.	https://www.lifecycleinitiative.org/activities/what-is-life-cycle-thinking/ and https://www.youtube.com/watch?v=o5o4Upxyb2Q
Here's an example of a charitable foundation doing sustainability work by providing equitable solar energy.	https://www.honnoldfoundation.org/films and https://youtu.be/vFhLPhWLTUg?si=8ttqRm1rJoDs mGk

2. Build your personal knowledge around sustainability. For example, learn about definitions of sustainability and the influence of stakeholder values, or find connection between the United Nations Sustainable Development Goals (SDGs) and your area of expertise, be it in your research or teaching. Include such connections in your class in some way (e.g., a calculation, a brief discussion of indicators, a case study, an open-ended complex problem, a

guest lecture, a role-play scenario), and be explicit in including all dimensions of sustainability in your assessments and discussions (i.e., economic, environmental, and social), as well as including the importance of values and ethics into such assessments. Recognize and emphasize that sustainability is the context for student learning and decision-making, rather than simply a convenient example for demonstrating theory.

3. Demonstrate/model engagement with others, especially those from different disciplines and those with other types of expertise than yours. Invite others into your classroom so that your students witness what collaboration looks like. Help students to recognize the importance of working across boundaries and to recognize and value the input and expertise of different disciplines.

Above all, remember that perfection is the enemy of the good. Give this a try, and

in doing so you will develop students' skills in complex problem solving and you'll join a growing movement of educators focussed on creating positive change.

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