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DOI
10.1016/j.sheji.2023.04.004

Publication date
2023

Document Version
Final published version

Published in
She Ji: The Journal of Design, Economics, and Innovation

she ji [ʃə: dʒi:]

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Keywords
Sustainable design
Design education
Future of design education
Circular design
Circular economy
Responsible design

Received
January 24, 2023
Accepted
April 23, 2023

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Abstract
The Future of Design Education working group on sustainability developed recommendations for integrating sustainability into higher education design curricula. The recommendations provide a foundation for design instruction, using well-established evidence-based tools, methods, and mindsets that apply to professional practice and support designers as advocates for environmental and social responsibility. The document identifies core ideas for sustainable design, organized under a set of topics. These topics include sustainability fundamentals; circular economy; whole systems thinking; sustainable innovation strategies; impact assessment, and laws and standards; and communication, collaboration, and leadership. A summary table captures each idea, along with corresponding discussion and learning outcomes (things students should know and do). Recommendations are tailored to three levels of study: for all design students, students expecting to practice in sustainable design, and students in elective or advanced study. Resources for such study are also included.

http://www.sciencedirect.com/journal/she-ji-the-journal-of-design-economics-and-innovation
https://doi.org/10.1016/j.sheji.2023.04.004

Introduction

Professional designers and design educators are slowly acknowledging that sustainability is no longer a "nice to have" but a requirement in design.[1] Environmental problems like the climate crisis are frequently in the news, and the Intergovernmental Panel on Climate Change (IPCC) reports that industry is falling far short of the change needed to keep global warming below 1.5 °C.[2] Society increasingly demands fixes to social problems such as gender, race, and wealth inequality through imperatives like the United Nations Sustainable Development Goals.[3] These environmental and social problems are linked. As Lara Cushing and her colleagues pointed out, "more unequal societies have more polluted and degraded environments,"[4] and in those societies, disadvantaged people suffer far more exposure to pollution, which hurts their health as well as educational and career achievement.[5] Thus, fixing environmental problems can help reduce social inequality, and fixing social inequality can help reduce environmental problems. They reinforce each other. We cannot wait for one to be fixed before starting the other; we must pursue them in parallel.

Natural, social, economic, and technical systems come together in design.[6] Many designers work to solve these problems and build a better world. They have created thousands of successful sustainable products and businesses, tools, and methods for design practice.[7] However, these are a tiny fraction of the billions of products designed and manufactured every year. Industry must transform to integrate sustainability at scale. The IPCC projects that climate change alone will cause the extinction of 18–30% of all species on Earth by 2100,[8] and there are other problems such as eutrophication, habitat loss, and more. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) estimates one million species risk extinction, and that "human actions threaten more species with global extinction now than ever before."[9]

For industry to integrate sustainable design at scale, design education must integrate sustainability at scale. So, how does design education accomplish that? Specifically, what overarching vision(s) should ground design programs, and what specific curricular topics and competencies should be taught at what levels? The Future of Design Education working group on sustainability made recommendations regarding these issues.

Sustainable Design Practice

Because of the sheer scale, difficulty and complexity of sustainability problems, industry and academia are still learning how to design for it. Many sustainable design tools, methods, and mindsets have evolved over the years—and evolution will continue. The following section lists key sustainable design approaches in a brief historical summary, before discussing integration into education.

In 1972, Victor Papanek and R. Buckminster Fuller argued for designers to realize their responsibility in *Design for the Real World*.[10] This built on earlier critiques by Vance Packard and others that industry drove consumer culture.[11] In 1987, The United Nations Rio Summit published *Our Common Future*,[12] often called "the Brundtland Report," providing the most commonly-used

1 Tania Humphries-Smith, "Sustainable Design and the Design Curriculum," *Journal of Design Research* 7, no. 3 (2009): 259–74, https://doi.org/10.1504/JDR.2008.024194; Michael W. Meyer and Don Norman, "Changing Design Education for the 21st Century," *She Ji: The Journal of Design, Economics, and Innovation* 6, no. 1 (2019): 13–49, https://doi.org/10.1016/j.sheji.2019.12.002; Ena Voûte et al., "Innovating a Large Design Education Program at a University of Technology," *She Ji: The Journal of Design, Economics, and Innovation* 6, no. 1 (2019): 50–66, https://doi.org/10.1016/j.sheji.2019.12.001.

2 Hans-Otto Pörtner et al., "Climate Change 2022: Impacts, Adaptation and Vulnerability" (report, IPCC WGII Sixth Assessment Report, 2022), https://www.ipcc.ch/report/ar6/wg2/.

3 United Nations, *Sustainable Development Goals* (New York: United Nations, 2015), https://sustainabledevelopment.un.org.

4 Lara Cushing et al., "The Haves, the Have-Nots, and the Health of Everyone: The Relationship between Social Inequality and Environmental Quality," abstract, *Annual Review of Public Health* 36 (March 2015): 193, https://doi.org/10.1146/annurev-publhealth-031914-122646.

5 Nanhua Zhang et al., "Early Childhood Lead Exposure and Academic Achievement: Evidence from Detroit Public Schools, 2008–2010," *American Journal of Public Health* 103, no. 3 (2013): e72–77, https://doi.org/10.2105/AJPH.2012.301164.

6 Fabrizio Ceschin and İdil Gaziulusoy, *Design for Sustainability: A Multi-level Framework from Products to Socio-technical Systems* (London: Routledge, 2019), https://doi.org/10.4324/9780429456510.

7 Alastair Fuad-Luke, *The Eco-Design Handbook: A Complete Sourcebook for the Home and Office*, 3rd ed. (London: Thames & Hudson, 2009).

8 Hans-Otto et al., "Climate Change 2022."

9 IPBES, *Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*, ed. E. S. Brondizio et al. (Bonn, Germany: IPBES secretariat, 2019), 207, https://doi.org/10.5281/zenodo.3831673.

10 Victor Papanek, *Design for the Real World: Human Ecology and Social Change* (New York: Pantheon Books, 1972).

11 Vance Packard, *The Waste Makers*, Pocket Cardinal ed. (New York: Pocket Books, 1967).

definition of sustainable development for industry: “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” It suggested product designers aim for energy efficiency. During this time, Life Cycle Assessment (LCA) gradually emerged as one of the most powerful tools because it quantifies environmental impacts, enabling evidence-based eco-design.[13] The 1990s saw the creation of the first methods specific to product design, such as the Ecodesign Strategy Wheel,[14] which helps consider sustainable design strategies at all life cycle stages of a product. Sim Van der Ryn and Stuart Cowan defined ecological design as expanding beyond Brundtland’s future generations of humans to be “any form of design that minimizes environmentally destructive impacts by integrating itself with living processes.”[15] Soon after, Janine Benyus suggested biomimicry as a method to align all industry with nature[16] and John Tillman Lyle proposed the concept of “regenerative design,”[17] which not only minimizes negative impacts but aims for positive impacts that restore ecosystems. William McDonough and Michael Braungart’s 2002 book *Cradle to Cradle*[18] took this further, arguing that designers should maximize beneficial impact instead of minimizing negative impact. They should integrate biomimicry with industrial ecology for closed-loop systems of healthy production. They also argued that sustainability should not be mechanistically utilitarian, but should come from care and empathy. It should answer the question: “how do we love all the children of all species — not just our own — for all time?” A decade later, *Cradle to Cradle*’s paradigm was combined with business sensibilities in the Circular Economy[19] to align economic incentives with economic benefits.

During the 2010s, the field of design expanded beyond products to business strategy, government policy, and larger socio-technical systems as a general process with broad applications under design thinking.[20] Transition Design[21] operated on this higher scale to help organizations transition from unsustainable to sustainable practices. At the same time, the United Nations developed its Sustainable Development Goals (SDGs).[22] New economic models were proposed, such as Doughnut Economics[23] to unite planetary boundary environmental goals[24] with UN SDG social goals. Degrowth economics[25] questioned the idea that companies and economies must always grow, and that circular economies can ever adequately decouple economic growth from material consumption. In the 2020s, designers have begun exploring tools for diversity and inclusion, such as the Designer’s Critical Alphabet,[26] which prompts designers to reflect on who is at the design table, with what privileges, and how they can bring marginalized people into the design process.

Sustainable design best practices continue to evolve. The purpose of this article is not to recommend the future of sustainable design tools and methods; others have already suggested roadmaps for sustainable design research.[27] But we cannot wait for perfection and must — as best we can — integrate sustainability into design education and practice now. Because the climate, biodiversity, and other crises are time-dependent and urgent, educators must immediately scale up training on the tools and methods we have (while researchers and industry seek better methods). All three groups must work together to continually improve iterations.

12 World Commission on Environment and Development, *Our Common Future: World Commission on Environment and Development* (Oxford: Oxford University Press, 1987), https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf.

13 Jeroen B. Guinée et al., “Life Cycle Assessment: Past, Present, and Future,” *Environmental Science and Technology* 45, no. 1 (2011): 90–96, https://doi.org/10.1021/es101316v.

14 Han Brezet and Caroline van Hemel, *Ecodesign: A Promising Approach to Sustainable Production and Consumption* (Delft: United Nations Environmental Programme, 1997).

15 Sim Van der Ryn and Stuart Cowan, *Ecological Design* (Washington, D.C.: Island Press, 1996), 18.

16 Janine M. Benyus, *Biomimicry: Innovation Inspired by Nature* (New York: HarperCollins, 1997).

17 John Tillman Lyle, *Regenerative Design for Sustainable Development* (Hoboken, NJ: John Wiley & Sons, 1996).

18 William McDonough and Michael Braungart, *Cradle to Cradle: Remaking the Way We Make Things* (New York: MacMillan, 2002).

19 Ellen MacArthur Foundation, “Towards the Circular Economy Vol. 1: An Economic and Business Rationale for an Accelerated Transition” (report, Ellen MacArthur Foundation, 2013), https://ellenmacarthurfoundation.org/towards-the-circular-economy-vol-1-an-economic-and-business-rationale-for-an.

20 Tim Brown, *Change by Design: How Design Thinking Transforms Organizations and Inspires Innovation* (New York: HarperCollins, 2009).

21 Terry Irwin, “Transition Design: A Proposal for a New Area of Design Practice, Study, and Research,” *Design and Culture* 7, no. 2 (2015): 229–46, https://doi.org/10.1080/17547075.2015.1051829.

22 United Nations, *Sustainable Development Goals*.

23 Kate Raworth, *Doughnut Economics: Seven Ways to Think Like a 21st Century Economist* (White River Junction, VT: Chelsea Green Publishing, 2017).

24 Johan Rockström et al., “A Safe Operating Space for Humanity,” *Nature* 461, no. 7263 (2009): 472–75, https://doi.org/10.1038/461472a.

25 Giacomo D’Alisa, Federico Demaria, and Giorgos Kallis, eds., *Degrowth: A Vocabulary for a New Era* (New York: Routledge, 2014).

Designers have great power in creating the products, services, and systems that either cause problems or drive sustainability solutions. The impact of design — both positive and negative — results not only from *what* is created and the problems it addresses, but *how* it is developed, built, used, and disposed of. This includes materials — not only what materials, but how they are extracted and processed. It includes the energy and resources required to use the product, and whether the product's end of life results in reuse, remanufacturing, recycling, or other scenarios. Finally, it includes interactions with all the people involved across the value chain. Choices made at each step in the design process lead to positive and/or negative outcomes, both direct and indirect, in the short- and long-term.

Yet the power of designers is limited. Design is merely one strand in the web of modern industrial culture, which includes materials, supply chains, business models, marketing and advertising, regulations, infrastructure, consumer culture, and more. For example, a recycled and recyclable product cannot be designed without sourcing recycled materials, nor without the collection and processing infrastructure to recycle it at end of life. Repairable and long-lasting products cannot be economically competitive without supporting business strategies. A product designed for existing scales can become unsustainable when overconsumed. For example, overuse of energy efficient products can cause greater energy consumption due to a lack of accompanying changes in economic or marketing conditions — the "rebound effect."[28] Economics and laws (or lack thereof) frequently constrain designers by prioritizing property rights over environmental health and human rights.[29] Some aspects of today's culture are technocentric and consumerist, encouraging people to fulfill their needs by buying things rather than making personal connections or engaging in spiritual contemplation.[30] Global-scale sustainability reports such as the IPCC's climate assessments and the IPBES's biodiversity assessments barely mention product design, focusing mostly on energy generation, material production and waste, transport systems, economics, government policy, and society. These other fields may have more individual power to address the largest environmental and social challenges.[31] Indeed, some argue that product designers cannot produce sustainability in isolation. They must collaborate with many partners — up and down management chains, across value chains, and across disciplines — to pursue shared visions. When business executives, collaborators, and legislators fail to value sustainability, designers must use communication and leadership skills to convince them.

For Transition Design, designers work directly on larger-scale business, legal, social, and technical systems. But, unlike a product designer changing the wall thickness of a part, they cannot make direct changes to these systems. Instead, they are facilitators bringing interdisciplinary stakeholder teams through their design processes. Thus, for these designers, communication and leadership skills are analogous to a product designer's CAD or rendering skills. They depend on others to implement.

Economic limits on design are especially complicated. Popular opinion often assumes that sustainability adds costs without commensurate business value. However, many well-established strategies for cost efficiency, such as lean manufacturing and energy efficiency, are also unacknowledged profitable

26 Lesley-Ann Noel, "The Designer's Critical Alphabet," Critical Alphabet, accessed May 29, 2023, for more information, see https://criticalalphabet.com/about/.

27 Jeremy Faludi et al., "A Research Roadmap for Sustainable Design Methods and Tools," *Sustainability* 12, no. 19 (2020): 8174, https://doi.org/10.3390/su12198174.

28 Frank Figge, William Young, and Ralf Barkemeyer, "Sufficiency or Efficiency to Achieve Lower Resource Consumption and Emissions? The Role of the Rebound Effect," *Journal of Cleaner Production* 69 (April 2014): 216–24, https://doi.org/10.1016/j.jclepro.2014.01.031.

29 Thomas Piketty, *A Brief History of Equality* (Cambridge, MA: Harvard University Press, 2021).

30 Krystle Ontong, "Addressing the Negative Impact of Consumerism on Young People by (Re)Awakening Their Spirituality through Sense of Place," *South African Journal of Higher Education* 32, no. 4 (2018): 199–214, https://doi.org/10.20853/32-4-2787.

31 Paul Hawken, ed., *Drawdown: The Most Comprehensive Plan Ever Proposed to Reverse Global Warming* (New York: Penguin Books, 2017).

sustainability strategies.[32] Numerous studies document that sustainable strategies improve the bottom line, reduce legal risk, and raise brand value.[33] Today, 99% of CEOs of the largest companies say sustainability is important to their business success.[34] When the maximization of short-term shareholder profit conflicts with ideal environmental and social action, some companies change their business models and governance structures. For example, the Mondragon Corporation, which is a worker-owned cooperative with semi-democratic self-governance, has been financially successful for nearly 80 years and employs over 70,000 people. Increased operating risks resulting from the climate and environmental crises are also becoming economic concerns. Institutional investors (for example, BlackRock at $10 trillion) now exert shareholder pressure on management to prioritize sustainability.[35]

Thus, the alignment between long-term financial and sustainability performance has never been clearer. It leads to a talent gap, with demand for sustainable design skills outweighing supply.[36] At the same time, young people demand that their schools, governments, and employers privilege sustainability and climate action as an existential imperative,[37] as illustrated by Greta Thunberg-inspired climate crisis strikes.[38]

Teaching Sustainable Design

Sustainability has been included in product and industrial design curricula in some higher education for decades. TU Delft has taught it since the 1990s. Professional development programs have offered training in sustainable design for some time, usually as a special topic taught by consulting firms, such as Pré Sustainability's courses on LCA, or Biomimicry 3.8's courses on bio-inspired design. Some entrepreneurship incubators now provide resources for sustainable design training, such as the Kickstarter Environmental Resources Center[39] and VentureWell Tools for Design and Sustainability.[40] Overall, however, few college design programs require classes dedicated entirely to sustainable design, mentioning the topic only briefly in other courses or assigning it elective status.[41] Lack of faculty expertise is a frequent reason for this shortfall, as is the view that—when it comes to finding graduates jobs in industry—sustainability is less important than existing aesthetics or engineering curriculum.[42] This lack of curriculum—especially required curriculum—means that design education fails to act at the scale required to face current ecological crises.

Meanwhile, other fields are incorporating sustainability into their college curricula. The Lemelson Foundation's Engineering for One Planet (EOP)[43] initiative is driving sustainability as a core tenet of the engineering profession. EOP recognizes that the sustainability talent gap cannot be bridged without changes in engineering education—changes that prepare all graduates with essential sustainability skill sets and mindsets.[44] Its framework of learning objectives and teaching guides does not prescribe one curriculum. Instead, it recommends a menu of existing curricular examples from many sources, which align with the engineering accreditation standards of the Accreditation Board for Engineering and Technology (ABET) and the United Nations Sustainable Development Goals. EOP co-developed the framework to protect and improve the planet and life through collaboration with hundreds of

32 Paul Hawken, Hunter Lovins, and Amory Lovins, *Natural Capitalism: The Next Industrial Revolution* (Oxfordshire, England: Taylor & Francis, 1999), 63.

33 Tensie Whelan et al., "ESG and Financial Performance: Uncovering the Relationship by Aggregating Evidence from 1000 Plus Studies Published between 2015–2020" (report, NYU Stern Center for Sustainable Business, 2021), 7–9, https://www.stern.nyu.edu/sites/default/files/assets/documents/NYU-RAM_ESG-Paper_2021%20Rev_0.pdf.

34 UN Global Compact and Accenture, "The Decade to Deliver: A Call to Business Action" (report, by United Nations Global Compact, New York, 2019), 23, https://www.accenture.com/content/dam/accenture/final/capabilities/strategy-and-consulting/supply-chain---operations/document/Accenture-The-Decade-to-Deliver-a-Call-to-Business-Action.pdf.

35 Larry Fink, "The Power of Capitalism: Larry Fink's Annual 2022 Letter to CEOs," *Blackrock*, accessed May 29, 2023, https://www.blackrock.com/us/individual/2022-larry-fink-ceo-letter.

36 LinkedIn Corporate Communications, "Our 2022 Global Green Skills Report," *LinkedIn Economic Graph*, February 22, 2022, https://news.linkedin.com/2022/february/our-2022-global-green-skills-report.

37 SOS International, "Students, Sustainability, and Education: Results from a Survey with Students in Higher Education around the World," Students Organizing for Sustainability International, February 2021, https://sos.earth/survey-2020/.

38 Mattias Wahlström et al., eds., "Protest for a Future: Composition, Mobilization, and Motives of the Participants in Fridays for Future Climate Protests on 15 March, 2019 in 13 European Cities" (report, Protest for the Future, July 2019), available at https://www.researchgate.net/publication/334745801.

39 Kickstarter, "Kickstarter Environmental Resources Center," 2018, accessed May 29, 2023, https://www.kickstarter.com/environment.

40 VentureWell, "Tools for Design and Sustainability," *VentureWell*, accessed May 29, 2023, https://venturewell.org/tools_for_design.

41 Matthew Watkins et al., "Sustainable Product Design Education: Current Practice," *She Ji: The Journal of Design, Economics, and Innovation* 7, no. 4 (2021): 611–37, https://doi.org/10.1016/j.sheji.2021.11.003.

stakeholders from academic, corporate, government, and non-profit sectors. As a community of practice, EOP brings together academics and other stakeholders for mutual support in developing the future of engineering education. This is a model that design education can follow.

While most studies relevant to sustainable design education are anecdotal, some have been quantitative. The largest studies focused on engineering education[45] or a general education in sustainability.[46] Some studied innovation in business education,[47] but only a few targeted design.[48] One by Jeremy Faludi and Cindy Gilbert[49] quantitatively and qualitatively studied curriculum, teaching, and administrative support—it provided a basis for the Future of Design Education curricular recommendations that follow.

Student Skill Levels

Sustainable design competencies include an array of approaches to understanding impacts and interconnection, all to reduce the negative and increase the positive impacts of design decisions. Sustainability must be integrated into all design practices, but there are many different fields of expertise and not everyone will be an expert. Curriculum planners must consider what subjects to teach and the competency levels required for roles in industry. Giving students cursory exposure to sustainability could result in educational "greenwashing," where advertised or perceived competencies in methods, tools, and metrics far exceed actual skills. In turn, graduates could unintentionally greenwash products and services they go on to design. Just as evidence-based metrics are critical to the credibility of sustainable design, they are important to the credibility of design education too. Bloom's taxonomy can be used to assess level-specific competencies related to sustainability.[50] Technical knowledge and skills in very specialized fields can change quickly, but some concepts endure—particularly basic principles. Educators must stay current with industry standards for tools, methods, and metrics by asking practitioners for advice.[51]

Educators and employers cannot expect all students to become experts in all topics, or all faculty to stay current with advances in all sub-specialties. There are at least three levels of competency to consider in sustainable design education: what all design students should know and do; what future practitioners in sustainable design should know and do; and what advanced or elective students might study.

The Development of Recommendations for Sustainable Design Education

The working group on sustainability included practitioners and faculty, all with years of experience in sustainable design. Co-leaders (one practitioner and one academic) selected members to mirror the diversity of practice, types of institutions, geographic location, and designer demographics. The working group also reached out to relevant organizations (e.g., the Ellen MacArthur Foundation) and other disciplines for advice.

Table 1 outlines the core ideas for sustainable design the working group identified.

42 Jeremy Faludi and Cindy Gilbert, "Best Practices for Teaching Green Invention: Interviews on Design, Engineering, and Business Education," *Journal of Cleaner Production* 234 (October 2019): 1246–61, https://doi.org/10.1016/j.jclepro.2019.06.246.

43 The Lemelson Foundation and VentureWell, "The Engineering for One Planet Framework: Essential Learning Outcomes for Engineering Education" (Powered by Lemelson Foundation, prepared in partnership with VentureWell, 2020), https://engineeringforoneplanet.org.

44 Cindy P. Cooper, "The Surge in Climate Action Requires a Surge in Green Talent, but How on Earth to Fill the Gap?," The Lemelson Foundation, April 13, 2022, https://www.lemelson.org/the-surge-in-climate-action-requires-a-surge-in-green-talent-but-how-on-earth-to-fill-the-gap/.

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45 David T. Allen et al., "Benchmarking Sustainable Engineering Education: Final Report" (report, Syracuse University, May 2005), available at https://doi.org/10.13140/RG.2.2.21852.13446.

46 Armin Wiek, Lauren Withycombe, and Charles L. Redman, "Key Competencies in Sustainability: A Reference Framework for Academic Program Development," *Sustainability Science* 6, no. 2 (2011): 203–18, https://doi.org/10.1007/s11625-011-0132-6.

47 Janine Fleith de Medeiros, Jose Luis Duarte Ribeiro, and Marcelo Nogueira Cortimiglia, "Success Factors for Environmentally Sustainable Product Innovation: A Systematic Literature Review," *Journal of Cleaner Production* 65 (February 2014): 76–86, https://doi.org/10.1016/j.jclepro.2013.08.035.

48 Humphries-Smith, "Sustainable Design and the Design Curriculum."

49 Faludi and Gilbert, "Best Practices for Teaching Green Invention."

50 Eric Pappas, Olga Pierrakos, and Robert Nagel, "Using Bloom's Taxonomy to Teach Sustainability in Multiple Contexts," *Journal of Cleaner Production* 48 (June 2013): 54–64, https://doi.org/10.1016/j.jclepro.2012.09.039.

51 Johannes Christoph Behrisch, Mariano Ramirez, and Damien Giurco, "Ecodesign in Industrial Design Consultancies—Comparing Australia, China, Germany and the USA," in *DS 68-5: Proceedings of the 18th International Conference on Engineering Design (ICED 11)* (London: DRS, 2011), 1–11, https://www.designsociety.org/publication/30573/; Jeremy Faludi and Alice M. Agogino, "What Design Practices Do Professionals Use for Sustainability and Innovation?," in *DS92: Proceedings of the DESIGN 2018 15th International Design Conference* (London: DRS, 2018), 2633–44, https://doi.org/10.21278/idc.2018.0180.

Table 1 **Core ideas.**

Fundamentals of Sustainability	• All humans depend on nature and are part of it; all products and services require materials and energy that come from nature and must safely return to it. Thus, without sustainable design, there will be no other fields of design. (Industrial, mechanical, information, and textile design etc., must all consider sustainability.) • Economics depends on society, which depends on the environment. All designers must take responsibility for their decisions, which impact these interdependent systems, even when effects are unintentional. • Design choices cause environmental and social impacts in all life cycle phases (raw materials, manufacturing, transport, usage, and end of life). Designers have a responsibility to consider all these different phases to produce the most positive effects possible, moving away from exploitative design to regenerative design. • Social and environmental consequences are intertwined. Design must not reinforce oppressive cultures and must bring about environmental justice.
Circular Economy	• Designing for the circular economy means aiming to eliminate mining and landfill through wise resource cycling: designing for long life, sharing, repair, upgrade, reuse, remanufacture, service models, refurbishment, and recycling or composting in simple and intuitive ways. • Circular design strategies often require new business or economic models (e.g., product service systems, product stewardship) to transition to a circular economy. Such strategies require designers to partner and collaborate with stakeholders in all aspects of the system (e.g., business planners, governments, external partners, etc.).
Whole Systems Thinking	• When assessing impact and making design choices, designers must consider the whole system from the earliest stages of the design process. This includes the life cycle and larger context, as well as technical and social issues at different levels. Considering the whole system helps avoid unintended consequences, such as improving one component of the system to the detriment of the whole. It also helps designers to decide what changes have the greatest leverage.
Sustainable Innovation Strategies	• There are tools, methods, and strategies unique to sustainable design that drive innovation at different points and levels in the design process (e.g., certification checklists, LCA, design for recycling). Designers should learn these and choose the most appropriate ones for the job at hand. They should also improve tools and methods as needed.
Impact Assessment, and Laws and Standards	• Environmental and social impact can be quantified, or at least qualitatively assessed. Design priorities and choices should be based on evidence from such assessments. • Laws establish minimum sustainability performance in various regions and industries. Certifications establish higher levels of expectations that designers can and should achieve. Designers can also design better policies, laws, and certifications.
Communication, Collaboration, and Leadership	• Designers can lead through the things they do and the things they produce. They can also advocate across value chains, management hierarchies, and broader society to drive evolving systems of sustainable production, consumption, policy, culture, and living.

The recommendations that follow provide detail on sustainable design issues related to natural systems, as introduced in the article on systems and as a counterpart to articles on "Pluriversal Futures for Design Education" (social systems) and "Navigating Design, Data, and Decision in an Age of Uncertainty" (technical systems) in this special issue of *She Ji*. The goal of the Future of Design Education working group on sustainability is to fill sustainability knowledge gaps in design education at three levels of study and to suggest relevant learning outcomes across design specializations taught in higher education, engineering universities, art schools, and professional training programs. It is up to institutions to frame topics appropriately for their undergraduate and postgraduate students.

Table 2 provides an overview of recommended curricular content at each level of student specialization:

- **[All]** Is critical to all design education and recommended as a requirement, even in programs without a specific sustainability focus.
- **[SD]** Is not required for designers in general but is required for a sustainability-specific class or program.
- **[EA]** Is not required but is a valuable topic, suitable for elective or advanced study.

Any of these topics can be taught at the graduate or undergraduate level by varying the depth and degree of emphasis.

Table 2 **Curriculum topics students should know and do.**

Fundamentals of Sustainability		**All designers and engineers need a basic level of sustainability literacy to recognize problems, proximate causes, and approaches to create regenerative, equitable and resilient outcomes for all life on Earth. Designers and engineers who specialize in sustainable design need deeper understanding of applications, as well as how to measure success, set goals, and make tradeoffs or find synergies.**
[All]	**Definitions of environmental, social, and economic sustainability**	List definitions of environmental, social, and economic sustainability (e.g., Brundtland report, Earth Charter, or other). For higher education levels, write a definition of sustainable design relevant to the student's region and context, using concepts from Impact Assessment, and Laws and Standards.
[All]	**Planetary boundaries and the Anthropocene**	Describe the planetary boundaries and list which ones can be impacted negatively and/or positively by a given design.
[All]	**Sustainable Development Goals**	Recognize which United Nations Sustainable Development Goals (UN SDGs) can be impacted negatively and/or positively by a given design.
[All]	**Environmental and social impacts of design and designers' responsibility to improve them**	Qualitatively list the environmental and social impacts of a given design and acknowledge the designer's responsibility to improve them. (For greater depth, see Impact Assessment, and Laws and Standards.)
[All]	**Equity in access and resource distribution, both globally and within countries**	Identify inequalities in access and resource distribution, globally and nationally, relevant to a given design.

[SD]	**Natural resource extraction limits and issues**	List the main natural resource extraction limits and problems relevant to a given design. (See also Impact Assessment, and Laws and Standards).
[SD]	**Production and consumption impacts across life cycle phases (A)**	Qualitatively describe the environmental and social impacts of a product's production and consumption across all life cycle phases (e.g., materials, production, use, and end of life).
[SD]	**Production and consumption impacts across life cycle phases (B)**	Redesign a product to improve its production and consumption impacts, and describe its expected benefits and limitations. (See also Impact Assessment, and Laws and Standards.)
[SD]	**Ecosystem cycles and/or services**	Describe key ecosystem cycles (carbon, nitrogen/phosphorus, water, soil creation, etc.) and/or ecosystem services such as water purification, crop pollination, and other provisioning, regulating, cultural, or support services performed by ecosystems. Also describe how the cycles or services drive design priorities.
[SD]	**Diversity and inclusion in design practice**	Practice diversity and inclusion in the composition of design teams, classes, departments, and engagement of users or other stakeholders. Assess how well the group reflects the people *with* and *for* whom they design, and suggest ways to improve representation in decision-making.
[EA]	**Doughnut Economics**	Describe Doughnut Economics and apply it to design by creating a design that can benefit various categories of impacts.
[EA]	**Environmental justice in design**	Design a product, service, or system to drive environmental justice and justify its features and/or qualities by expected benefits.
[EA]	**History of sustainable design movements**	Explain how the history of sustainability movements relating to design can guide today's designers.
Circular Economy		**The Circular Economy or Cradle to Cradle thinking aims for restorative or regenerative value and design. It emphasizes effective resource use: eliminating mining of new resources, waste, pollution, and ecosystem disruption by circulating resources through the economy many times in closed loops at their highest value. This approach replaces an old linear economy of *mining* > *production* > *use* > *landfill or incineration*. The Circular Economy combines products and services in circular business models; for example, ownership of physical products may stay with the manufacturing company.** **This approach requires designers to know more about materials, product lifespan, business models, and service systems. In addition, shifting to business models in which ownership stays with the manufacturer extends the relationship between the company and users across time. Designing for the circular economy requires the engagement of stakeholders in the design process, and a systems approach.**
[All]	**Think regeneratively rather than linearly**	Describe the difference and compare the implications of a linear product system and a regenerative circular system.
[All]	**Visualize product or service resource flows**	Visualize the flow and impact of raw material, components, products, and services for insights, both at the scale of user needs and system implications for circular design.

[All]	**Design for extended life (durability, repair, upgrade)**	Describe how circular design strategies (including durability, repairability, upgradability) extend product lifetimes, tighten resource loops, and eliminate waste. (See also Sustainable Innovation Strategies.)
[All]	**Design for multiple use cycles**	Propose design strategies for multiple use cycles (e.g., reuse, refurbish, sharing) while retaining value in a circular economy.
[All]	**Select materials to enable circularity and minimize impacts**	Select product materials and manufacturing processes that enable circularity and improve impacts (health, environmental, and social) across the full product life cycle and recovery.
[All]	**Product-service systems for circular economy**	Propose product-service systems that allow for recovering and looping back products, components, and materials into a circular economy.
[SD]	**Circular Economy business models**	Apply circular business models, such as product service systems, that aim at fully closing resource loops and integrating products with services at scale. (See also Sustainable Innovation Strategies.)
[SD]	**Circularity assessment**	Differentiate between weak circularity (or greenwashing) and strong circularity by quantifying consequences of circular offerings at the system level and over multiple use cycles, using a circularity assessment and/or life cycle assessment. (See also Impact Assessment, and Laws and Standards.)
[SD]	**Design for extended life (durability, repair, upgrade)**	Apply design for repair, upgrade, refurbishment, and durability strategies to a product and its service system. (See also *Sustainable Innovation Strategies*.)
[SD]	**Enroll user in maintenance, recovery, etc.**	Propose strategies for engaging users in product care, maintenance, and recovery, whether shared or owned.
[SD]	**Manage collaboration with external stakeholders for a circular business model**	Identify, map, facilitate, and manage the collaboration among external stakeholders required to operationalize a circular economy business model. (See also Communication, Collaboration, and Leadership.)
[EA]	**Regenerative solutions**	Design regenerative solutions that give back more than is taken from ecosystems, including solutions that reverse climate change, biodiversity loss, waste, and pollution at scale.
[EA]	**Product-service system maps**	Create maps and models of product-service systems (PSS) to understand existing scenarios and propose better alternatives; this may include studying an unsustainable product-service system to improve its sustainability.
[EA]	**Embed sensors and data types for circularity**	Identify where and how to embed data types and sensors into a system so they create feedback loops that enable more efficient operation of circular systems (e.g., to recover parts).
[EA]	**Circular economy policy**	Identify where and how to change policies, internal or external, so they economically incentivize circularity (e.g., to recover products or materials).
[EA]	**Work with alternative socio-economic models**	Compare the advantages and disadvantages of alternative socio-economic models, such as Doughnut Economics, degrowth capitalism, or others, and propose new alternatives.

Whole Systems Thinking		**Designers should see and map dynamic cause-and-effect relationships in systems as reflections of complexity in the real world. Systems thinking is a holistic approach to design decision-making. It assesses impact at all levels to ensure that outcomes meet overarching sustainability goals, identify new opportunities, and innovate.**
[All]	**Identify system-wide implications of design decisions**	Explain the relationships among design decisions, impacts, broader systems, and opportunities, including the system-wide implications of a specific design decision.
[All]	**Map full life cycle of products, services, and materials**	Construct a simple analogue system map to illustrate relationships and identify insights that could lead to interventions.
[All]	**Assess functionality and impact at system level**	When evaluating functionality and impact, conduct assessments at the level of the whole system to avoid making the whole worse by improving a part.
[SD]	**Cause and effect relationships**	Identify cause-effect relationships, consequences of action, and impact assessments to take responsibility for professional decisions.
[SD]	**Systems thinking in design**	Apply a systems mindset to design challenges, ensuring that solutions are developed from a whole-systems perspective.
[SD]	**System mapping**	Draw a basic system map communicating the impacts that product, material, and general design decisions have on the natural and social world.
[SD]	**Life cycle and functionality**	Draw a product life cycle and/or value chain map to demonstrate material flows and the impact of these on the natural and social world.
[EA]	**Manage trade-offs in complex systems**	Manage trade-offs and/or synergies within systems, such as between embodied material impacts, end of life options, different use cases, etc.
[EA]	**System dynamics**	Map or quantitatively model systems dynamics using causal loop diagrams, including stocks and flows and feedback loops.
[EA]	**Root cause analysis**	Identify “upstream” root causes to “end-of-pipe” symptoms in a system, including physical, economic, policy, and cultural, and suggest design interventions to improve them.
[EA]	**Consequential system design**	Create a system-level design intervention based on consequential impact (i.e., anticipating the changes in customer demand or other consequences of the main intervention).
Sustainable Innovation Strategies		**Designers should understand and apply sustainable design tools, methods, and strategies to innovate products and services in concrete, measurable ways. This includes using insights from impact assessments, whole systems thinking, and circular economy strategies to select specific tools and methods.**
[All]	**Recognize that sustainable innovation tools and methods exist**	Identify different sustainability-specific design tools, methods, or strategies for different circumstances and life cycle stages, such as those listed below. Include impact assessment tools or methods they should be paired with to avoid greenwashing.

[SD]	**Ecodesign Strategy Wheel**	Use the Ecodesign Strategy Wheel ("sustainable design thinking") to ideate sustainable design solutions and identify opportunities for greatest improvement across different stages of a product's life cycle.
[SD]	**Material choice**	Select sustainable materials for a product and compare benefits and limitations.
[SD]	**Cradle to Cradle or Circular Economy strategies**	Apply Cradle to Cradle or Circular Economy tools and methods (e.g., design for durability, repair, reuse, recycle, compost, etc.) to the design of a product or system. Evaluate the advantages and disadvantages of various strategies. (See also Circular Economy.)
[SD]	**Circular sustainable business strategies**	Explore various sustainable business models (e.g., turn a product into a product service system, build a social benefit model etc.), and compare likely environmental, social, and economic outcomes.
[SD]	**Energy effectiveness**	Apply energy effectiveness strategies to the design of a product or system, and compare their advantages and disadvantages.
[SD]	**Behavior change**	Apply persuasive design strategies to a product, service, or system, to drive more sustainable user behavior. Describe both the expected benefits and potential ethical concerns.
[SD]	**Integrate impact assessment and systems**	Choose impact assessment and systems thinking methods to apply alongside sustainable ideation methods to guide innovation and avoid greenwashing. Consider a variety of assessments to understand strengths and limitations of different strategies.
[SD]	**Match design tools to their different purposes**	Recognize that different sustainable design methods, tools, and strategies are used for different purposes (e.g., goal setting, research, analysis, ideation, decision making, communication, and industry-specific context). Use the best one(s) for the job at hand.
[EA]	**Biomimicry or bio-inspiration**	Apply biomimicry to a product, service, or system design. Describe advantages and disadvantages of the intervention. Perform field studies in nature and describe how they inspire and motivate sustainability.
[EA]	**Frugal innovation**	Apply extreme affordability strategies to the design of a product, service, or system to make it accessible to the world's poorest. Explain what is gained and lost in reducing consumer cost.
[EA]	**Lightweighting**	Apply lightweighting to a product design and describe its advantages and disadvantages versus circular design strategies to reduce material consumption.
[EA]	**Factor Ten Engineering**	Apply Factor Ten Engineering (10xE) to the design of a product, service, or system. Explain the energy and resource savings, as well as consequences for other aspects of the design.
[EA]	**Integrate legal or certification requirements**	List legal and certification requirements applying to a design. Use them to help choose sustainable innovation and assessment strategies.
[EA]	**Practical details of executing strategies**	Describe and integrate the practical details of executing sustainable design strategies in a real-world context (e.g., business relationships, multiple stakeholders, reverse logistics, etc.). Describe how it limits and enables design decisions.

Impact Assessment, and Laws and Standards		Designers must understand and apply environmental and social impact assessments to set evidence-based design priorities and choose between design options based on evidence. They should balance trade-offs between different types of impacts or find beneficial synergies.
[All]	**Read existing assessments to set priorities or make choices**	Read and interpret a life cycle assessment (LCA), Environmental Product Declaration, or scorecard specific to a product category to set design priorities and/or make informed decisions between design options.
[SD]	**Fast-track LCA**	Apply a streamlined ("fast track") Life Cycle Assessment to a product or service using dedicated LCA software, lookup tables, or tools within other design software (e.g., SimaPro, GaBi software, IDEMAT spreadsheets, or SolidWorks Sustainability plugin).
[SD]	**Assess environmental impacts in all life-cycle stages**	Apply a specific impact assessment method (e.g., ecological footprint, LCA or others, such as product-specific scorecards) to assess the environmental impacts of a product across its entire life cycle, including raw material extraction, manufacturing, packaging and transportation, use, and end of life.
[SD]	**Debunk greenwashing**	Find or perform assessments to debunk greenwashing in sustainability claims.
[SD]	**Social impact assessment**	Describe a social impact assessment and how it would be applied to a product, service, and supply chain.
[SD]	**Describe limits of assessment methods**	Describe the limitations of various environmental or social sustainability assessment methods and how to work around them to make informed decisions.
[SD]	**Describe key laws**	Describe important environmental and social sustainability laws relevant to the designer's field, such as Restriction of Hazardous Substances (RoHS); Waste from Electrical and Electronic Equipment (WEEE); Registration, Evaluation, Authorization and Restriction of Chemical (REACH); and the EcoDesign Directive. Apply them to a design project.
[SD]	**Integrate assessments into product development**	Decide when and how to integrate sustainability assessments into standard product development processes. Use the insights to inform design decisions.
[SD]	**Balance tradeoffs between different impacts**	Choose among design alternatives, balancing trade-offs between different types of impacts, or finding beneficial synergies between them.
[EA]	**Full LCA: EPD / ISO 14000**	Apply a full Environmental Product Declaration or ISO 14000 series compliant life cycle assessment to a product or services, using dedicated LCA software or similar tools.
[EA]	**Circularity assessment**	Apply a circularity metric to assess the amount of resources and financial value recovered across multiple product or material lifetimes.
[EA]	**Health hazard assessment**	Apply a material or chemical toxicity hazard assessment on a product or service.
[EA]	**MIPS**	Apply a Material Input per Unit of Service (MIPS) assessment to a product or service.

[EA]	**Repairability assessment**	Assess a product's repairability, using French Repairability Index, iFixit, Joint Research Council, disassembly map, or other tools.
[EA]	**UN SDG assessment**	Assess a product, service, company, or value chain for its contributions to (and detriments to) specific targets in various United Nations Sustainable Development Goals.
[EA]	**Certification or ecolabel**	Apply a sustainability certification (ecolabel) assessment to a product, service, company, or value chain. Some legitimate certifications include Cradle to Cradle for products like furniture or textiles, Electronic Protection Environmental Assessment Tool (EPEAT) for computers and peripherals, EnergyStar for appliances, EU Ecolabel or EcoMark Japan for multiple product categories.
[EA]	**Social impact certification**	Apply or explain results of an existing social sustainability certification for a business operation. Some legitimate certifications include Fair Trade, Global Compact, Global Reporting Initiative (GRI), or SA8000.
[EA]	**Country-specific/field-specific laws**	Identify and integrate country- and field-specific environmental, health, and social laws into design decisions.
[EA]	**Design better policy**	Write a suggested law, certification, or policy to improve the sustainability of a field, or contribute to research that improves sustainability laws, certifications, or policies.
Communication, Collaboration, and Leadership		**Designers are often not the ultimate decision makers, but they are well-positioned to use their design and leadership skills to drive sustainable innovation. They must develop engaging visions and narratives of sustainability and advocate for policy and cultural change. Studies show that organizational barriers are often more significant than economic or technological barriers. Thus, communication and leadership are needed to activate stakeholders, both internal (peers and executives) and external constituencies (value chain partners, customers, governments, and others). Storytelling helps create a shared vocabulary, reframes problem and solution spaces, and helps sell ideas. Collaboration skills boost team effectiveness and help members cope with the stress of addressing some of the world's greatest challenges without giving up for easier pursuits. Leadership motivates individuals and teams to overcome obstacles.**
[All]	**Sustainability vocabulary**	List key sustainability vocabulary (see all other curricular topic areas) and describe them in value-added framing (the benefits they provide in design).
[All]	**Recognize greenwashing**	Differentiate between genuine steps toward sustainability and greenwashing.
[All]	**Sustainability visions**	Create engaging visions, stories, and value propositions for sustainability and the circular economy.
[All]	**Sell sustainability within team**	Argue persuasively with colleagues and executives for the value of sustainability in a project.
[All]	**Personal code of conduct**	Write an ethics-based personal code of conduct related to design practice.
[All]	**Gather stakeholder feedback on (un)intended consequences**	Gather feedback from stakeholders to identify and address the (un)intended consequences and barriers of design decisions.

[SD]	**Build psychological safety among collaborators**	Apply methods and tools for building psychological safety among collaborators (e.g., empathy and nonviolent communication) to enhance team effectiveness and individual resilience, especially in hostile circumstances.
[SD]	**Sell sustainability to external teams**	Argue persuasively with external partners (e.g., up to clients, down to supply chain vendors, across to other partners) for them to contribute to a project's sustainability (e.g., by changing materials, production, end of life collection, etc.)
[SD]	**Organizational change and change management**	Describe methods and tools for change management and how to apply them to drive organizational change for sustainability in teams.
[SD]	**Reframing problems to reimagine them**	Question users, collaborators, executives, and other stakeholders to interpret their deeper needs, to broaden and refocus ideation on more effective and radical sustainable solutions.
[SD]	**Share knowledge, skills, and opportunities**	Describe best practices for sharing knowledge, skills, and opportunities with colleagues, partners, key suppliers, etc. to normalize approaches to sustainable design.
[EA]	**Debunk greenwashing**	Write analyses debunking greenwashing or verifying claims with science-based evidence and persuasive arguments.
[EA]	**Participatory design and co-design**	Apply participatory and co-design methods in projects to drive adoption of circular and sustainable solutions, especially with influential organizations, key suppliers, or with marginalized groups.
[EA]	**Building partnerships, breaking down silos**	To lead organizational change, describe how to build internal and external partnerships to break down silos and barriers across organizations (e.g., within value chains and across academic, government, NGO sectors).

Resources

The sustainability working group also developed a list of recommended curricular resources. Levels of clarity, depth, and ease of use vary widely among different books, videos, exercises, and other teaching tools. Table 3 lists recommended resources for each of the categories above. It is not a definitive or exhaustive list and is biased by what resources the authors are familiar with. However, it should help newcomers to sustainability integrate the topics into their coursework.

Limitations and Future Work

The working group on sustainability acknowledges that this article does not represent a definitive curriculum proposal. Its members encourage discussion in the wider sustainable design community to hone recommendations. While the working group was diverse, the educational background of its members was largely Euro-centric, which may limit the applicability

Table 3 **Resources.**

Fundamentals of Sustainability:
• Anthropocene and Great American Acceleration website, https://anthropocene.info/great-acceleration.php • *Design for the Real World* book (Papanek & Fuller, 1972)[52] • Designer's Critical Alphabet cards (Noel, 2020)[53] • Doughnut Economics Lab website, https://doughnuteconomics.org • Engineering for One Planet website, https://engineeringforoneplanet.org • EU Ecodesign guide website, https://sustainabilityguide.eu/ecodesign • Kickstarter Environmental Resources Center website, https://kickstarter.com/environment • Planetary Boundaries website, https://www.stockholmresilience.org/research/planetary-boundaries/the-nine-planetary-boundaries.html • SDG Compass website, https://sdgcompass.org
Circular Economy:
• Circular Design website, https://www.circulardesign.it • "Circular Economy Competencies for Design" article (Sumter et al., 2021)[54] • Doughnut Economics Lab website, https://doughnuteconomics.org • Ellen MacArthur Foundation / IDEO Circular Design Guide, https://www.circulardesignguide.com • European Commission Circular Economy Action Plan (2020) website, https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en • VentureWell Tools for Design and Sustainability (TFDS) online tutorials on design for circular economy and product service systems, https://venturewell.org/tools_for_design/design-lifetime-sharing/
Whole Systems Thinking:
• Online system mapping tools such as Loopy, https://ncase.me/loopy/v1.1/; or Kumu, https://kumu.io/ • *Systems One* book (Kauffman, 1980)[55] • Systems Thinker website, https://thesystemsthinker.com • Systems Thinking Design Pack website, https://educators.brainpop.com/printable/institute-play-design-pack-systems-thinking/ • *Thinking in Systems* book (Meadows, 2008)[56] • UNEP Life Cycle Initiative website, https://www.lifecycleinitiative.org • VentureWell TFDS Whole System Mapping method online tutorial, https://venturewell.org/tools_for_design/whole-systems-mapping/ • Why Social Ventures Need Systems Thinking (Kirsch et al., 2016)[57]
Sustainable Innovation Strategies:
• Delft Design Guide tutorials on Ecodesign Strategy Wheel, Cradle to Cradle, LCA, Base of the Pyramid, and more (Van Boeijen et al., 2020)[58] • Factor Ten Engineering Design Principles (Lovins et al., 2010)[59] • *Cradle to Cradle* book (McDonough & Braungart, 2002)[60] • Okala Practitioner tutorials on Ecodesign Strategy Wheel, LCA, circular economy, and more (White et al., 2013)[61] • Presidio Sustainability Booster for Business Model Canvas website, https://www.presidio.edu/blog/business-sustainability-booster/ • Triple Layered Business Model Canvas method (Joyce et al., 2016)[62] • AskNature biomimicry database website, https://AskNature.org • Biomimicry DesignLens method (Biomimicry 3.8, 2013)[63] • VentureWell TFDS online tutorials on material choice, systems, energy, circular economy, behavior change, business models, certifications, and more, https://venturewell.org/tools_for_design/introduction/

52 Papanek, *Design for the Real World*.
53 Noel, "The Designer's Critical Alphabet."
54 Deborah Sumter et al., "Key Competencies for Design in a Circular Economy: Exploring Gaps in Design Knowledge and Skills for a Circular Economy," *Sustainability* 13, no. 2 (2021): 776, https://doi.org/10.3390/su13020776.
55 Draper L. Kauffman, *Systems One: An Introduction to Systems Thinking* (Waltham, MA: Pegasus Communications, 1980).
56 Donella H. Meadows, *Thinking in Systems: A Primer* (White River Junction, VT: Chelsea Green Publishing, 2008).
57 Vanessa Kirsch, Jim Bildner, and Jeff Walker, "Why Social Ventures Need Systems Thinking," *Harvard Business Review*, July 25, 2016, https://hbr.org/2016/07/why-social-ventures-need-systems-thinking.
58 Annemiek G. C. van Boeijen, Jaap Daalhuizen, and Jelle Zijlstra, *Delft Design Guide: Perspectives, Models, Approaches, Methods* (Amsterdam: BIS Publishers, 2020).
59 Amory Lovins et al., "Factor Ten Engineering Design Principles" (report, published by Rocky Mountain Institute, 2010), https://rmi.org/insight/factor-ten-engineering-design-principles/.
60 McDonough and Braungart, *Cradle to Cradle*.
61 Philip White, Steve Belletire, and Louise St Pierre, *Okala Practitioner: Integrating Ecological Design* (Phoenix, AZ: IDSA, 2013).
62 Alexandre Joyce and Raymond L. Paquin, "The Triple Layered Business Model Canvas: A Tool to Design More Sustainable Business Models," *Journal of Cleaner Production* 135 (November 2016): 1474–86, https://doi.org/10.1016/j.jclepro.2016.06.067.
63 Biomimicry 3.8, "Biomimicry DesignLens: A Toolkit of Best Practices," accessed May 23, 2023, https://biomimicry.net/the-buzz/resources/biomimicry-designlens/.

Impact Assessment, and Laws and Standards:

- Cradle to Cradle certification resources website, https://c2ccertified.org/resources
- Global Reporting Initiative, "How to Use the GRI Standards" website, https://www.globalreporting.org/how-to-use-the-gri-standards/
- EPEAT certification online tutorial on VentureWell TFDS, https://venturewell.org/tools_for_design/measuring-sustainability/epeat-certification/
- *LCA: A Practical Guide for Students, Designers, and Business Managers* book (Vogtlander, 2014)[64]
- *Life Cycle Assessment: A Guide to Best Practices* book (Klöpffer & Grahl, 2014)[65]
- LCA professional software: SimaPro, https://simapro.com; Gabi, https://sphera.com/product-sustainability-software/; or OpenLCA, https://www.openlca.org
- LCA streamlined web apps: SustainableMinds, https://www.sustainableminds.com; LCA Calculator, https://www.lcacalculator.com
- LCA lookup tables and spreadsheet calculators: Ecolizer, https://ecolizer.be; Okala Practitioner LCA tables,[66] VentureWell TFDS calculator, https://venturewell.org/tools_for_design/measuring-sustainability/life-cycle-assessment-content/
- OpenLCA network partners website, https://www.openlca.org/partners
- SA8000 certification online tutorial on VentureWell TFDS, https://venturewell.org/tools_for_design/measuring-sustainability/sa8000-certification/
- *Guidelines for Social Life Cycle Assessment of Products* (Benoit et al., 2009)[67]
- UN Global Compact website, https://unglobalcompact.org
- UNEP Life Cycle Initiative website, https://www.lifecycleinitiative.org

Communication, Collaboration, and Leadership:

- *Crucial Conversations* book (Patterson et al., 2012)[68]
- *Harvard Business Review's 10 Must Reads on Change Management* book (Kotter et al., 2011)[69]
- *Making Shift Happen* book (Leuvan et al., 2022)[70]
- *Nonviolent Communication* book (Rosenberg, 2002)[71]
- *Reinventing Organizations*, Illustrated book (Laloux, 2016)[72]
- Team Effectiveness online worksheets from Re:Work / Google Project Aristotle, https://rework.withgoogle.com/print/guides/5721312655835136/
- US Federal Trade Commission "Green Guides" for greenwashing website, https://www.ftc.gov/news-events/topics/truth-advertising/green-guides

of recommendations to different contexts and the traditions they evoke. The working group also encourages more inputs from India, China, and Africa — inputs which might lead to a reframing of its recommendations.

The working group concedes that listing curricular topics and resources is not enough to change education. True change requires transformation of large institutions and industry. Future research on the resources and methods likely to accelerate both deep and broad adoption of sustainable design education is needed to make change at scale. The purpose of this article is to prompt dialogue, not to be exhaustive.

Another limitation of this article is that it discusses sustainable design as its own field, not as part of other engineering or design practices. While sustainability will continue as a specialization, it must also be integrated deeply into other fields, as mathematics is in the sciences. Future work should drive integration in both directions — integrating sustainability tools and methods into other design fields and using design methods from other fields to improve sustainability tools.

64 Joost G. Vogtlander. *LCA, A Practical Guide for Students, Designers, and Business Managers*, 2nd ed. (Delft: Delft Academic Press, 2014).

65 Walter Klöpffer and Birgit Grahl, *Life Cycle Assessment (LCA): A Guide to Best Practice* (New York: John Wiley & Sons, 2014).

66 White et al., *Okala Practitioner*.

67 United Nations Environment Programme, *Guidelines for Social Life Cycle Assessment* (Belgium: UNEP, 2009).

68 Kerry Patterson et al., *Crucial Conversations: Tools for Talking When Stakes Are High* (New York: McGraw-Hill Education, 2012).

69 Harvard Business Review, *HBR's 10 Must Reads on Change Management* (Boston: Harvard Business Press, 2011).

70 Nya van Leuvan et al., *Making Shift Happen: Designing for Successful Environmental Behavior Change* (Gabriola Island, BC: New Society Publishers, 2022).

71 Marshall B. Rosenberg, *Nonviolent Communication: A Language of Compassion* (Encinitas, CA: Puddledancer Press, 2002).

72 Frederic Laloux, *Reinventing Organizations: An Illustrated Invitation to Join the Conversations on Next-Stage Organizations* (Brussels: Nelson Parker, 2016).

Conclusion

In this article, the Future of Design Education working group on sustainability developed recommendations for sustainable design curricula. The recommendations aim to base design instruction on evidence-based tools, methods, mindsets that both support designer advocacy for social and environmental responsibility and are effective in professional practice. They include eleven core ideas for an overarching vision of sustainability in design and design education, plus learning outcomes organized in six categories for three levels of study. As best practices in sustainable design evolve, education should follow suit or even lead, but these recommendations will bring education up to the standards of currently well-established practices.

Regardless of whether these exact recommendations are followed, the central point is the necessity of integrating sustainability into design education, both academic and professional. The urgency of environmental and social challenges is obvious. But even for those privileged enough to be untouched by current problems, if the purpose of design is to satisfy people's needs in creative and beautiful ways, then the best way to fulfill that purpose is by designing to make the whole world more satisfying and beautiful. Not only for today's immediate users of one product, but also for everyone and everyplace touched by the system, across all future generations of all life. The goal of the Future of Design Education is to rapidly accelerate the transition to a better world, by challenging the design community to rapidly transform the way it educates. Today's students and industry practitioners need to start designing sustainable solutions today, not ten years from now. The knowledge and tools are already here, there is no better time or greater urgency to build them into the future of design education.

Declaration of Interests

There are no conflicts of interest involved in this article.

Acknowledgments

We thank those that initiated and supported the Future of Design Education initiative. These include Don Norman and others at the University of California San Diego Design Lab; Meredith Davis at North Carolina State University; IBM Global Design Group; and the World Design Organization. We also thank Simon Widmer at the Ellen MacArthur Foundation for initial conversations on the recommendations, and the academics and industry professionals who provided feedback on them.

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