Sustainability and Justice: Challenges and Opportunities for an Open STEM Education

Carrie Diaz Eaton,[1]* Kaitlin Bonner,[2] Karen Cangialosi,[3] Bryan Dewsbury,[4] Maggie Diamond-Stanic,[1] Jason Douma,[5] Michelle Smith,[6] Robin Taylor,[7] Jeremy Wojdak,[8] and Krystie Wilfong[9]

[1]Digital and Computational Studies and [9]Library and Information Services, Bates College, Lewiston, ME 04240; [2]Department of Biology, St. John Fisher College, Rochester, NY 14618; [3]Department of Biology, Keene State College, Keene, NH 03435; [4]Biological Sciences, Florida International University, Miami, FL, 33199; [5]Natural Sciences Area, University of Sioux Falls, Sioux Falls, SD 57105; [6]Department of Ecology and Evolutionary Biology. Cornell University, Ithaca, NY 14850; [7]RTRES Consulting, Knoxville, TN 37934; [8]Department of Biology, Radford University, Radford, VA 24142

ABSTRACT

Open educational resources, or OER, are teaching materials that reside in the public domain and are available under an open license. While the creation of high-quality materials and cyberinfrastructure to share these resources is important, OER are much more than static resource repositories. Vibrant OER communities function as collaboration hubs and often include librarians, instructional technologists, instructors, education researchers, funders, open-source software developers, and college administrators. Together, these individuals work as a community to respond to changes in the education landscape, support student learning impacts both in terms of cost savings and student retention, and solve issues related to broadly sharing open resources on the web. This essay provides general information about OER, describes communities developing OER for science, technology, engineering, and mathematics education, and presents insights about sustainability challenges. The sustainability challenges are organized according to multiple dimensions: cultural and social, economic and financial, and technological and environmental. In addition, OER provide important opportunities to address and promote social justice and open and accessible education philosophies. Knowing more about the OER landscape, sustainability challenges, and educational justice opportunities can help instructors use and contribute to this growing movement to reshape the landscape of undergraduate education.

INTRODUCTION

Open educational resources (OER) are defined as "teaching, learning, and research materials in any medium—digital or otherwise—that reside in the public domain or have been released under an open license that permits no-cost access, use, adaptation, and redistribution by others with no or limited restrictions" (The United Nations Educational, Scientific and Cultural Organization; see Table 1 for a list of common acronyms). For undergraduate biology instructors, OER may take many forms, including clicker questions, laboratory protocols, and short online videos. Here, we use an expansive definition of OER that also includes open-source software and models, as well as professional development and informal learning materials.

The most salient feature of OER is often their zero-cost promise to students. OER, by definition, are freely available to both use and contribute to. As a result, cost savings to institutions are a frequently talked-about benefit of OER (Lambert, 2018). The replacement of commercial learning materials with OER have saved undergraduate students millions of dollars nationally (Griffiths *et al.*, 2018). When data from K–12

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*Address correspondence to: Carrie Diaz Eaton (cdeaton@bates.edu).

TABLE 1. Acronyms commonly used in open education (additional organizational acronyms can be found in Supplemental Tables S1 and S2)

5R permissions	Retain, revise, remix, reuse, redistribute
DOIs	Digital object identifier
FMN	Faculty mentoring network
OEP	Open educational practices
OER	Open educational resources
RCN-UBE	Research Coordination Network for Undergraduate Biology Education
S-JEDI	Social justice, equity, diversity, and inclusion
SPARC	Scholarly Publishing and Academic Resources Coalition
STEM	Science, technology, engineering, and math

institutions, which often have to purchase learning materials, are included, the OER movement is estimated to have saved students, parents, schools, and governments at least $1 billion dollars worldwide (Allen, 2018).

Beyond issues of cost, and because they are broadly accessible, OER have a powerful influence on democratizing knowledge and empowering learners around the world (Bali *et al.*, 2020; Ossiannilsson *et al.*, 2020). OER increase access to educational content, particularly in emerging fields for which standard textbooks are not available (e.g., computational biology), improve the quality of materials, widen participation, and support scholarship that is transparent and that engages community more broadly (Caswell *et al.*, 2008; D'Antoni, 2009; Windle *et al.*, 2010; Hegarty, 2015; Henderson and Ostashewski, 2018). Additionally, students using OER perform better throughout courses, have improved end-of-course grades, and have decreased drop–fail–withdrawal rates. This outcome is particularly true for Pell recipient students (Hilton *et al.*, 2016; Colvard *et al.*, 2018).

The adoption and use of OER can be described by the OER life cycle (Clements and Pawloski, 2012; adapted from Pawlowski and Zimmermann, 2007; Figure 1). First, instructors create or find OER, then adapt them to a particular use case. Once instructors use these OER, they can refine them based on that implementation experience and then share them. While presented as a linear process in Figure 1, the OER life cycle is not always so linear in its exact order; however, the idea of presenting the adoption and use of OER as a life cycle is to encourage OER to be part of a broader community authoring and use movement. A key enabling feature of OER is that they are published with a set of permissions referred to as the 5Rs that allow educators to adapt the materials to their own unique instructional contexts. The 5Rs are the right to *retain*: the right to make, own, and control copies; *revise*: the right to edit and adapt; *remix*: the right to combine materials; *reuse*: the right to use resources publicly; and *redistribute*: the right to share copies with others (Wiley, 2014). The 5R permissions enable instructors to reshare their adaptations with the broader OER community, completing the OER life cycle and providing a mechanism for students to contribute to the knowledge commons (Jhangiani and DeRosa, 2017). OER also create the opportunity to form communities around teaching and learning through the material production, adaptation, and resharing process.

A subset of science, technology, engineering, and mathematics (STEM) higher education projects and OER-related organizations are referenced throughout this paper and are listed in Supplemental Table S2 with some additional information for readers. We include STEM projects more broadly, because biology education itself is multidisciplinary, including other STEM disciplines such as physics and mathematics. Readers can engage with these projects at a variety of levels. For example, instructors can participate in online professional development activities on Quantitative Undergraduate Biology Education and Synthesis (QUBES) Hub, publish undergraduate OER in the peer-reviewed journal *CourseSource*, and engage in conversations about race and racism in regard to OER and organizational practice through the RIOS Institute. We discuss immediate and emergent challenges that are facing OER communities along with some of the insights and potential paths forward. These insights are derived from a combination of lived experience, research, and synthesis, as well as emergent insights as a result of discussions in our community of practice.

Frameworks for Understanding the STEM OER Community

Institutions, journals, and online hubs that host OER grapple with questions such as: How can OER hubs provide free

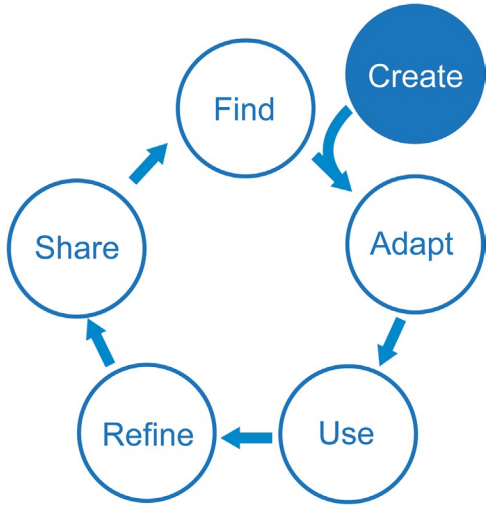

FIGURE 1. A simplified OER life cycle model for educational resources. Find: users find resources; Adapt: users adapt the resource or combine it with other resources to make it appropriate for their specific purposes; Use: users use the resource and assess student learning; Refine: users refine the resource after implementation; Share: users share the newly adapted and refined resource openly available for others to find, adapt, and use. Life cycle modified from Clements and Pawloski (2012; adapted from Pawlowski and Zimmermann, 2007).

Credits: Adapted from Attributes of Open Pedagogy from Bronwyn Hegarty, licenced under CC BY 3.0.

FIGURE 2. Eight attributes of OEP. Visual from Ontario Colleges OER Toolkit, licensed CC BY SA, and based on Bronwyn Hegarty's *Eight Attributes of Open Pedagogy* podcast transcript, from the Alberta Open Educational Resources Initiative, licensed under CC BY SA (Learning Portal and Institute for the Study of Knowledge Management in Education). For more information on OEP, see DeRosa and Robison (2017; Hoffman and Clifton, 2020).

resources to users while maintaining a financially sustainable resource? How can OER hubs stay relevant given technological shifts? How can they engage users in adopting and adapting OER? These questions have been similarly encountered by digital libraries—both those spawned anew in the digital age (e.g., National Science Digital Library) and those that transitioned to adopting an online presence from brick-and-mortar libraries (e.g., institutional libraries and repositories) (Chowdhury, 2014). Unfortunately, there is currently no well-established pathway that ensures clear answers to these questions, but it is clear that a shift from "library" to "dynamic community hub" is necessary (Chowdhury *et al.*, 2008; Chowdhury, 2014; Loach *et al.*, 2017). The evolution of the digital library from a static repository to a vibrant hub involves social and technological infrastructure that allows communication, sharing, modification of resources, and collaboration around the use of OER.

We use two frameworks to discuss the sustainability challenges facing OER and STEM education and research, with attention to the undergraduate STEM education and research community in particular. The first is Chowdhury's (2014) framework for the sustainability of digital libraries, with axes that include cultural and social sustainability, economic and financial sustainability, and technological and environmental sustainability. The second is Lambert's framework (2018) that proposes three principles of social justice: redistributive (allocation of material/resources to those who by circumstances have less), recognitive (recognition and respect for cultural and gender differences), and representational (equitable representation and political voice). As redistributive justice, OER save institutions and students money and increase student success (Lambert, 2018; Jenkins *et al.*, 2020). As recognitive justice, OER can enable faculty to tailor instructional materials that better represent the diversity of contributions to STEM (Lambert, 2018). As representational justice, OER, when combined with open educational practices enable students to participate in knowledge creation (Lambert, 2018; Bali *et al.*, 2020).

Each dimension of these frameworks touches on the cyberinfrastructure and collaborative technology, the developer, the user, and the data and content. In addition, they are intertwined with—and sometimes in tension with—a commitment to social justice, equity, and inclusion. Thus, we also explicitly address the aspirational impact OER could make on social justice, equity, diversity, and inclusion in STEM education transformation. Nurturing a dynamic community hub, fostering a diverse, vibrant, healthy, and resilient OER ecosystem requires us to consider our commitment to inclusivity and social justice (Figure 2). Using collaboration to achieve these goals is critical as we strive to meet the *Vision and Change* (American Association for the Advancement of Science, 2010) core competencies (modeling, interdisciplinarity, etc.), while promising to focus on, promote, and support the needs of historically marginalized students and faculty.

IMMEDIATE AND EMERGENT CHALLENGES FACING OER COMMUNITIES

Building a Diverse and Vibrant OER Ecosystem: Beyond Cultural and Social Sustainability

The social and cultural values of OER are essential for the sustainability of these resources and includes the perpetuation of the OER life cycle, wherein instructors *create*, *find*, *use*, *adapt*, *refine*, and *share* the adaptations broadly (Figure 1), and a cultural framework that values discovery, access, usage, and sharing of OER-related content (Chowdhury, 2014). The recognition of OER scholarship both at the institutional and disciplinary levels, as well as the structure to interact with peers around OER, make up the cultural framework for the sustainability of

the resources (Donovan *et al.*, 2015). If there is no community surrounding the use of these resources, then the OER life cycle fails, because adoption rates drop and the resources will not be used to maximum impact (Orr *et al.*, 2015).

On the surface, finding OER should present little issue. Instructors can look within institutional libraries, multidisciplinary OER hubs (e.g., OER Commons, managed by Institute for the Study of Knowledge Management in Education), journals (e.g., *CourseSource*), disciplinary OER hubs (e.g., QUBES Hub), as well as federated search engines which retrieve information from a variety of sources and provide real-time results (e.g., Mason OER Metafinder; see Supplemental Table S2 for more information on some of these organizations). However, to help faculty overcome the nuances of classroom adaptation and implementation, OER can be connected to discipline-based communities where discussions in informal settings and professional development and outreach in formal settings serve critical roles. Without this discipline-specific community support for OER adoption and implementation, digital libraries are at risk of becoming a museum of forgotten and stale exhibits. This challenge can be overcome by nurturing ecosystems of collaborators who rely upon, benefit from, and regularly contribute to the OER environment in their common areas of interest (de Langen, 2018).

Another major challenge to a vibrant OER ecosystem is completing the life cycle (i.e., resharing; Figure 1; Senn *et al.*, 2022). The barriers to completing the life cycle include: a lack of infrastructure for communicating experiences during the process of implementing and refining materials, the availability of appropriate venues for sharing adaptations, and variability in the scholarly value academic institutions place on sharing adapted materials. Here too, developing communities and engaging in discipline-specific professional development (e.g., CourseSource Writing Workshops and QUBES Faculty Mentoring Networks) can help instructors overcome barriers to resharing their materials (Farrell *et al.*, 2021). OER cyberinfrastructure (e.g., OER Commons and QUBES Hub) provides publishing outlets that offer indexing, DOIs, citation guides, and view/download metrics. All of these can help others recognize OER contributions as part of a tenure package, particularly at teaching-focused institutions and/or for teaching-stream faculty (Smith, 2018).

For the OER ecosystem to be successful, it is important to build community with particular attention to who we are including in order to ensure equity in access and usage of OER (both in openness and in compatibility with assistive technologies). We refer readers to recommendations from the communities building National Science Foundation (NSF)-funded research coordination networks for undergraduate biology (Diaz Eaton *et al.*, 2016) and the Center for Scientific Collaboration and Community Engagement (cscce.org). Both sets of recommendations provide information on how to build and support the kinds of communities needed for social/cultural sustainability. Furthermore, we need to ensure that open education resources, practices and communities not only address economic inequities, but foster "recognitive justice," that is, are culturally sensitive and inclusive of diverse perspectives (Lambert, 2018; Adam *et al.*, 2019). If instructors can create their own narratives in their own instructional materials, write materials that are aligned with universal design for learning practices (Hasley and Orndorf, 2021), and/or adapt an OER text and add diverse scientists' biographies and citations to the text, they are part of building a new narrative for higher education.

Furthermore, use of OER should be leveraged to support open educational practices (OEP; Figure 2). OEP emphasize participatory classrooms in which OER are not just about allowing access to knowledge, but also emphasize student agency and ownership of learning. Students can create and openly license content and therefore move from a model of information download to one in which they contribute their own ideas to a public knowledge commons (DeRosa and Robison, 2017). Providing opportunities for students, especially the marginalized, to construct and share knowledge is an especially potent way to empower those whose voices are often ignored (Hodgkinson-Williams and Arinto, 2017; Jhangiani and DeRosa, 2017). When a diversity of students and faculty are invited to participate in the practices of remixing and revising content, they can make these materials more representative and inclusive of a wide variety of people and perspectives, promoting what Lambert terms as "representational justice" (Hodgkinson-Williams and Arinto, 2017; Lambert, 2018).

This instructional flexibility of OER is already being leveraged by OER authors in emerging areas (active learning, interdisciplinarity, etc.) in which traditional texts are slow to respond to changes in the field. For example, the kind of curriculum that introduces open science and open data practices can naturally align with OEP in biology classrooms (Figure 2). As the community embraces these open practices, we should also keep in mind the inherent tensions of open work, such as student authorship crediting and labor, Indigenous data sovereignty as it pertains to open data (Rainie *et al.*, 2019), Oxford, and privacy issues in digital environments (Watters, 2014). Leaders and participants within organizations must grapple with how to conceptualize and prioritize the role of social justice, equity, diversity, and inclusion (here termed "S-JEDI" practices) in their commitment to STEM education. So far, traditional textbooks have been slow to respond to the call to create an antiracist, antibigoted, antisexist, anti-ableist, decolonized STEM curriculum. We see OER as a key lever in promoting such transformation for STEM education.

Operationalizing Justice: Centering Redistributive Justice in Economic and Financial Sustainability

Healthy, vibrant OER ecosystems are expensive and are currently underfunded and rely on volunteer labor. Besides the volunteer labor of OER authors discussed earlier, successful development of OER requires invisible labor to develop and maintain cyberinfrastructure (discussed more in *Collaboration: Addressing Technological and Environmental Sustainability*) and to organize the OER community. Open technology organizations rely heavily on volunteer labor to maintain community engagement and generate products (Dunbar-Hester, 2020). Academia as an enterprise also relies heavily on uncompensated, unrewarded, and/or undervalued service to govern institutions, to govern professional societies, and to maintain its publishing system—with disproportionate burden on women and Black faculty, Indigenous faculty, Latinx faculty, and other faculty of color (Hirshfield and Joseph, 2012; Hall, 2016). OER lie at the intersection of these worlds—the worlds of academic

institutions, publishing, and professional societies—and are therefore vulnerable to reinforcing inequities in labor (e.g., Columbia, 2016).

The OER community's commitment to being free for both users and contributors presents obvious difficulties by constraining the typical revenue streams that would otherwise help compensate for the labor required. In commercial and nonprofit systems either the submitter or the consumer typically pays for the costs of the publishing infrastructure. If free access for both the producers and consumers of OER is necessary to preserve equity, then funding structures must be reimagined for the OER environment. To address this essential issue, it is important to focus on *why* OER are "open" and for whom they are "open" (Hodgkinson-Williams and Trotter, 2018; Adam *et al.*, 2019). Questions that frame this discussion include: What are the implications for a vision of an open and accessible 21st-century educational experience? What are the potential benefits for students in an educational model that regularly uses OER as well as broader open educational practices and pedagogies? What is the commitment to S-JEDI for OER creators and distributors, and how does that affect an OER community's orientation to solutions for financial sustainability, who has access as a producer or consumer, and whether an OER's potential for transformative and liberating pedagogy/classroom experience is being met?

To answer some of these questions, we look to theory and research on the sustainability of nonprofit organizations (e.g., Stevens, 2002). The financial obstacles to sustainability could be reduced if OER communities—and the nonprofits who support them—work together on synergistic activities. While innovation funding is important early in the nonprofit life cycle, maturity requires different strategies that promote long-term base funding and support.

The typical nonprofit life cycle results in a lack of funding support if organizations do not continue to evolve. For dynamic OER hubs, which still operate in an innovative landscape, the financial sustainability solutions will likely be innovative as well. These solutions may include tapping into new funding streams by encouraging discipline-based projects to seek philanthropic foundation funding, following in the footsteps of organizations like OpenStax (Ernst, 2015). Another possibility is connecting OER to discipline-based research communities that could use the community of practitioners and educational reforms as fertile test beds for instructional materials aligned with education research questions, a model successfully used by *CourseSource* (e.g., Pelletreau *et al.*, 2018; Dauer *et al.*, 2019). Finally, an affiliation with a university would allow funded projects to trade indirect fees for access to shared institutional resources, such as affordable health insurance and administrative systems for hiring employees and managing grants—a model used by Science Education Resource Center in its relationship to Carleton College. Another alternative is to gain the support of institutional consortia, which is the model of some broad OER repositories such as the Open Textbook Library (2022) at the University of Minnesota. Universities with institutional commitments to educational access might welcome affiliation with projects aligned with their missions and strategic investments. Finally, projects should consider collaboration on cyberinfrastructure—which promises to broaden impact, accelerate innovation, and lower costs.

Collaboration: Addressing Technological and Environmental Sustainability

The computational resources needed to support recent shifts in the way scholars and educators in biology are interacting with technology in the conduct of research, teaching, and learning (Thistlewaite and Daniels, 2016; Chen *et al.*, 2018) demonstrate significant challenges to technological sustainability in an environment marked by continual innovation. Increasingly, faculty and students expect to—or at least desire to—access information and resources immediately through online searches (Biddix *et al.*, 2015). Furthermore, scientists are now more inclined to treat resources as dynamic entities that emphasize interaction between humans and technology, as well as among the human practitioners. The ability to adapt and customize instructional materials and computational tools to new environments has become a critical characteristic for evaluating the usefulness of resources in the practice of modern science.

OER are both a product of the evolving educational technology landscape and a potential solution to the needs of the communities that operate within it (Butcher and Hoosen, 2012). The OER movement emphasizes open access to and adaptability of quality academic resources. Development and dissemination of these materials is, by nature, an iterative process requiring the interaction of a community of practitioners. Likewise, the cyberinfrastructure of an OER hub needs to be responsive to the same needs of the community to sustain participation. Therefore, social and technological designs coevolve over time to best serve each other's needs. While resource production is important, a vibrant OER ecosystem requires a continued investment in this infrastructure in order to move away from a focus on static resource repositories, engage communities of practice, and keep the OER ecosystem accessible to all.

Cyberinfrastructure sharing among a variety of organizations can help to reduce expenses and benefit each participants' cyberinfrastructure development and maintenance expenditures. When multiple communities are trying to reach the same audience and have similar cyberinfrastructure needs, we might characterize them as competitors. Instead, we suggest a reframing so that this is an opportunity for collaboration. *CourseSource* and Systemic Initiative for Modeling Investigations & Opportunities with Differential Equations moved their cyberinfrastructure to QUBES Hub because of the benefits it offers all parties. *CourseSource* now takes advantage of the collaborative cyberinfrastructure for its writing workshops. *CourseSource* authors can now take advantage of the open practices built into the publishing system, for example, the ability to share updated versions of their course materials. SIMIODE will benefit from reducing the duplication of cyberinfrastructure management efforts involved in maintaining its own separate hub, which it had done for many years. Both will also lower their cyberinfrastructure operating cost, while BioQUEST (the nonprofit that manages QUBES Hub) benefits from the additional contracts key to maintaining the cyberinfrastructure (Akman *et al.*, 2020). The migration also builds a larger community of users for all projects.

An Open and Equitable Higher Education Ecosystem

The relationship between the higher education course curricula and their constituent content has historically revolved around restrictive access. In the early days of the American university, many professors literally read from books they wrote with the

expectation that students would be able to recite them from memory (hence the term "recitation") during an examination (Zimmerman, 2020). The advent of the Humboldtian model of the research university in the early 20th century privileged a small cadre of researchers as the medium through which students, and sometimes the public (through informal lectures), came to understand the world around them (Albritton, 2009). This model relied on the assumption that information and knowledge were not ubiquitous, and a premium of some sort had to be paid to access this information, either through tuition (which allowed access to the professors) or through the cost of the books they wrote. The expansion and common acceptance of college textbook use was simply a further codification of this limited access model.

OEP seeks to challenge this relationship by democratizing the ways in which key stakeholders in the higher education classroom engage and interrogate information. In doing so, important questions pertaining to equity are raised, the answers to which reframe how we think about and approach our pedagogy. Whose ways of knowing are privileged when curricula are constructed? What voices and perspectives are absent from the narratives? What specific pedagogical practices are being enacted that positions students to be agentic interrogators of what they encounter during courses and in the future?

In the third question lies the opportunity for OEP to be the framework through which education becomes a vehicle for critical consciousness (Freire, 1970; Figure 2). The notion that information and knowledge are living things to be engaged and interrogated and not static monuments to be accepted is crucial in preparing students to be civically engaged citizens (Dewey, 1916). It is also a formative experience for both practitioners and students on deconstructing the ways in which shared power can lead to more equitable outcomes for the classroom. In this light, OEP transcend teaching students how to remix and reconstruct textbook material but also includes the critical ways in which information, regardless of source, should be consumed and responded to. By empowering students with the agency to contribute new ideas from their own unique perspectives, OEP can nurture an "educational culture of questioning" (Giroux, 2020), which is the foundation for a functional democracy.

NEXT STEPS FOR OER COMMUNITIES

Many of the collaborative projects outlined earlier as well as a series of activities aimed at confronting social justice for OER were funded by the RIOS Institute. The timing of these conversations about S-JEDI–minded OER for biology education has never been more relevant. Recently, many organizations RIOS supports have found themselves called to reorient and serve an increased demand in the midst of the COVID-19 crisis, while also feeling compelled to respond to the renewed protests in support of Black lives across the nation and the related #ShutDownAcademia and #ShutDownSTEM movements (ShutDownSTEM.com) by centering S-JEDI principles in their organizations and actions.

Our response to these social movements and our general commitment to equity and justice represent a key philosophical shift in OER work going forward. We are excited about the conversations we have begun, but there is more critical community-building work to do. The invitation to connect with other like-minded organizations and OER leaders is open and broad—just sign up to become a network member via the RIOS webpage on QUBES Hub (riosinstitute.org). We are committed to keeping this conversation open and centered on collaborations and issues of social justice, equity, and inclusion, and we welcome all those who share our mission. We plan to continue our virtual professional development series, and we invite you to join us.

As the RIOS Institute and our broader community strive to catalyze change in undergraduate STEM education, we are reminded to focus on, promote, and support social justice for STEM. Content alone is not sufficient to move education forward equitably toward its goals—we need to center people, talk about pedagogy, and create communities to shape a healthy and diverse ecosystem (Figure 2). With this grounding, we can reconsider how we might reimagine other axes of sustainability. Thus, our goal is to build and support a diverse community of leaders (including librarians, instructional technologists, instructors, education researchers, funders, OER hubs, open-source software developers, professional societies, journal editors, and college administrators) who strive to center accessibility, equity, and inclusivity while exploring sustainability challenges, innovating solutions, promoting sustainable online hubs for OER, and collaborating to preserve and grow what the STEM education community has built.

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