

Gala: An Open-Access Platform for Interactive Learning With Sustainability Case Studies

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Abstract—Sustainability science has been gaining traction within academic research and teaching over the past few decades, and it is now entering a phase of greater maturity as a discipline, with links to sectors beyond the academy including energy, finance, advocacy, development, design, construction, agriculture, and healthcare. Concurrently, the growth of the internet has spurred innovation in platform development. This convergence has generated technology-enabled opportunities for training sustainability scholars and practitioners grounded in active learning pedagogies. Case studies are one active learning strategy becoming established within the fields of environment and sustainability. However, the traditional case study form and mode of delivery, which excel at a retroactive analysis of strategic decision-making and outcomes, can create challenges for teaching about issues involving emergent technologies and rapidly changing scientific and social dimensions. This article describes one novel platform, called Gala, for teaching and learning about sustainability science through case studies that address these challenges. Gala closely integrates text and multimedia components, is easily updated, and embraces content consumers as content creators and vice versa. We also report here the results of one pilot study that investigated differences between graduate and undergraduate student interactions with different case components. Results indicate that both groups heavily used the case narrative, but varied in their use of multimedia components. Such insights into patterns of case use are informing decisions about improvements to Gala and directions for future case production, teaching, and assessment, in order to create better tools for teaching and learning about sustainability.

Index Terms—Authoring tools, collaborative learning tools, learning platform, open access, sustainability education, user-generated learning content.

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I. INTRODUCTION

SUSTAINABILITY science harnesses the power of the scientific method to understand interactions between human and natural systems, and to chart pathways for meeting human needs over multiple generations while reducing poverty and maintaining Earth's life support systems [1], [2]. This ambitious new science emerged in circa the early 2000s following several decades' worth of progressive thinking about the relationship between economic and social development and the finite capacity of Earth to accommodate natural resource consumption [3], [4]. Since then, the field has continuously worked to consolidate and better define a broad research and teaching agenda, with degree programs and courses in sustainability proliferating across higher education [5], [6]. However, despite substantial and growing interest in the field, sustainability science still lacks a widely agreed-upon curriculum [7]. Encouragingly, the field is homing in on a set of competencies for graduates of sustainability programs [8]–[11], and there is general agreement that effective sustainability education must prioritize active and experiential learning over more passive pedagogies (i.e., lectures) [12]–[15].

Case studies are one active learning strategy that has been identified as promising for sustainability education [10], [16]. They are not a new method, as they have long-established pedagogical use in fields such as law, business, and medicine, but in recent years, they have found increasing use and relevance in teaching for sustainability and environmental education. However, typical case studies have several characteristics that hinder the wide adoption of the method for sustainability and environmental education in the 21st century. For one, most case studies are still published as textual narratives, commonly as pdf files. While text-based cases can be very effective, they are unable to take advantage of web-based enhancements that can increase student engagement and the intellectual depth of content, such as visual and auditory media and tools for data visualization and manipulation. In addition, the static text is more difficult to update, which creates challenges for timely teaching about dynamic sustainability issues.

Education also broadly demands an inclusive approach, as inclusive practices are known to be beneficial for all students, especially for those from underrepresented groups. Inclusion is particularly important for sustainability education—given sustainability's wide purview, all-hands-on-deck ethos, and global relevance—that traditional case study pedagogy does

not always enable [17], [18]. Inclusion can mean including content about and relevant to diverse groups of people, especially historically marginalized communities, and telling stories that challenge dominant narratives. It can also mean providing more accessible content, with explicit design for learners with disabilities and presentation in plain language (as opposed to disciplinary jargon). At a deeper level, inclusion necessitates changing established processes and systems in order to open up the scholarship to a greater number of people and a broader range of perspectives [19]. For teaching materials and research publications, this means expanding authorship beyond faculty experts to students, practitioners, and other nonfaculty actors within and outside of universities. In addition, inclusion implies creating a tighter relationship between research and teaching, with cutting-edge research informing instructional materials, and insights from the classroom feeding back into research.

This article describes an innovative web-based platform for teaching and learning with sustainability case studies, called Gala [20], that aims to address some of these deficits. Gala was conceived and built at the University of Michigan by the Michigan Sustainability Cases (MSC) initiative, and it has been in use primarily at the School for Environment and Sustainability, though it has been used in other units and at other institutions. The platform was developed with two goals in mind: 1) to bring case studies into the fields of environment and sustainability as an engaging and effective pedagogy; and 2) to re-imagine the form of case studies by bringing them online and adding multimedia elements to make cases more inclusive, adaptable, and immersive. Gala also breaks down established distinctions between instructors and learners in that every user can be, in turn, a reader, a teacher, and an author. There are no restrictions on who can author a case or create a learning group and deploy cases. (“Deployment” in the Gala lexicon means directing a group of learners to the case study for a defined instructional event.)

Since its inception, Gala has undergone targeted evaluations to determine how it is working and for whom in order to inform its development. In this article, we report results from one of these evaluations that have provided insight into the different ways that undergraduate and graduate students interact with Gala. We conclude with a summary of what we have learned and a discussion of future work.

II. CURRENT PLATFORM LANDSCAPE

Before describing the platform, it is helpful to place Gala in context. The move to online content creation, distribution, and consumption over the last few decades has stimulated a burst of experimentation in online platforms for learning and scholarly communication. Individual platform-building efforts vary widely in the problems they address, the approaches that are taken to solving those problems, the financial and other support available, and the practices that define by whom and for whom the content is created and shared. In general, these platforms strive to bring teaching, learning, and research off the printed page and into a digital space, opening up new content

forms and new options for (a)synchronous ideas exchange in the process. These experiments represent the future of learning and scholarly communication—a trend that has been accelerated by the current COVID-19 pandemic—but they have yet to consolidate into a well-designed, networked, and well-supported ecosystem [21]. Given this reality, we first briefly survey the online platform landscape in order to provide a sense of how Gala relates to other platforms. The categories and trends described in the following are for illustrative purposes only and should not be construed as an attempt to authoritatively classify online platforms.

We begin with the term learning platform, which itself lacks a widely accepted definition. The Organisation for Economic Co-operation and Development (OECD), though focusing on economic transactions, provides a helpful description of an online platform: “. . . an online platform is a digital service that facilitates interactions between two or more distinct but interdependent sets of users . . . who interact through the service via the Internet” [22]. If we consider a service that facilitates interactions among instructors, learners, researchers, and other professionals for the purposes of education, this serves reasonably well as a definition of a learning platform. For this brief overview, we divide learning platforms into three categories: 1) learning management systems (LMSs); 2) massive open online courses (MOOCs); and 3) other content providers.

An LMS is a software system for structuring a course online [23]. LMSs typically have various tools for managing a course and mediating interactions between many learners and usually one instructor, including communication tools (e.g., discussion boards, and chat rooms), lesson planning tools (e.g., learning modules), assessment tools (e.g., quizzes and assignment submission), and more. Examples include Canvas, a commercial platform developed and supported by Instructure, and Moodle, an open-source platform originally developed by Martin Dougiamas [24], currently managed by MoodleHQ and supported by a network of more than 80 partner companies [25].

MOOCs are online education tools that deliver courses to many people at one time, often thousands per course. The courses are created by various universities and made available to learners from around the world, thereby connecting many learners to many institutions. Because of their sheer size and waxing influence within higher education, we include MOOCs as a separate category. MOOC providers typically have their own LMSs for distributing content and interacting with learners. MOOCs began as free online courses made available to anyone with an interest in university-level learning, including vocational learners looking to upskill and hobby learners engaging in learning for its own sake [26], [27]. However, low course completion rates and business model challenges have forced MOOC providers to shift focus in recent years to offer more corporate training and fee-based programs leading to academic credentials or credit [27]. The well-known examples of MOOC providers are edX, a nonprofit, open-source provider founded by Harvard University and the Massachusetts Institute of Technology (MIT) [28], and Coursera, a for-profit provider founded by Stanford University professors Daphne

Koller and Andrew Ng. Both edX and Coursera deliver content primarily through prerecorded lectures, which are supported by exercises and discussion boards. Each provider offers a series of certificates, specializations, and degree programs as an alternative to traditional, residential university programs.

Finally, because of the variety in platform design and purpose, we include all other learning and publishing platforms under the category of other content providers. This part of the landscape is ever-changing, as platform-building efforts come and go in response to user needs, developer interest, and available funding [21], [29]. In terms of features and content, these platforms blur the line between scholarly communication (i.e., publishing) and teaching and learning. (Although some might argue that this distinction has always been somewhat dubious.) Features run the gamut from authoring and editing interfaces to processes for review, to annotation, to user analytics, to assessment tools—and not every platform has the same suite of features. Manifold [30] is one example that publishes scholarly books in the humanities and social sciences. The open-source platform from the University of Minnesota mimics conventional printed books, but adds features for displaying videos and other media as well as annotation and commenting, and accommodates an iterative writing process leading to the final publication of a version of record. Thus, the platform brings together many authors and many readers. A very different example is QUBES Hub, an instructor-oriented platform for supporting teaching and learning in quantitative biology through shared resources, methods, and best practices [31]. Among its features is an open educational resource database that supports version control, allowing multiple authors to build upon contributed materials; groups that support community building and collaboration; and faculty mentoring networks that convene faculty to help in pedagogical adoption and adaptation for their teaching environment. QUBES Hub thus facilitates interactions among many biology and mathematics faculty from many institutions, spanning a range of organizational complexity from groups of faculty to partners that can encompass multiple groups, projects, and resources.

As described in the following, Gala also belongs in the category of other content providers, as it includes a suite of features for authoring new scholarly material, interacting with existing material, and assessing learner outcomes. In this way, Gala facilitates interactions among many researchers (i.e., case authors), instructors, and learners, with no hard boundaries between these groups.

III. GALA: AN OPEN-ACCESS, OPEN-SOURCE PLATFORM FOR CASE STUDIES

A. Platform Development and Technical Description

Gala began in 2015 as an engaging custom front-end to a WordPress website, but as our user experience design became increasingly different from a classic “article,” we pushed against that platform’s limits. We struggled to present a case that was structured as a single rich text document with the fidelity we

desired. Thus, it proved necessary to build out our own database back-end that supported structured data, allowing us to implement, rapidly iterate, and refine an immersive reading experience.

Gala is a database-driven web application for authoring, reading, and discussing media-rich case studies. It is built with the Ruby on Rails web application framework and centered on a dynamic front-end using React.js, which serves both as the view on a case for collaborative study and as its graphical editing interface. Gala’s source code is licensed under the open-source MIT license and published on Github [32]. A Gala case study is a complex, structured data type consisting of a central record for metadata, *Case*, which has a one-to-many polymorphic relationship with *CaseElements*: Pages of multiple types, as well as Podcast episodes. Each Page has many Cards, which contain one to two paragraphs of the narrative to which Edgenotes (i.e., embedded media elements) can be attached. Edgenotes are tied to specific highlighted snippets of the case text, and appear inline, alongside the Card to which they are attached.

B. Case Components

Gala’s design and suite of features developed over several years in response to feedback from users and an expanding sense of the platform’s potential. The basic structure and case components (cover page, narrative, Edgenotes, engaged learning exercise, teaching guide, and supplementary multimedia) have been retained since the early prototype, but they have been refined, and several new features have been added. In the following, we describe the basic components of cases and their evolution.

When users select a case, they are first taken to the *cover page*, which includes the title and author list, a summary, the table of contents, and learning objectives. Learning objectives did not appear during early iterations of the platform design. These were added later to improve pedagogical robustness and to subsequently provide a link to sustainability competencies, e.g., [8].

The heart of each case study is a textual *narrative*, which is broken into pages and cards (see Fig. 1). Segmenting information in this way creates a logical, flexible structure that can accommodate any learning module, and it takes advantage of chunking, the idea that grouping content into smaller, more manageable portions aids in information processing and retention [33]. The narrative lays out the protagonist and central question of each case, followed by stakeholder perspectives and/or complicating factors related to the sustainability issue. At the end of the case, users are typically asked to make a decision or propose a solution. Although many narratives follow an “and, but, therefore” structure [34], some authors have taken creative approaches. For example, one case study tells the story of an experiment to install urine-diverting toilets through a fictional (though realistic) email exchange between an environmental engineer and a campus housing director [35].

Multimedia components called *Edgenotes* are displayed alongside the text throughout the narrative. Edgenotes serve multiple functions. Some clarify or reinforce the material presented in the case while others are jumping-off points for further exploration. They include images, videos, data visualizations, links,

← Overview Conversation Deploy this Case

Dioxane Plume Pollution

Global Community

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A Knock at the Door

RESPOND

One unseasonably warm February 2016 morning in Ann Arbor, Michigan, Wesley Pate received a knock on his door. When he answered, Pate was greeted by Dan Bicknell, who ran the environmental consultancy [Global Environmental Alliance](#). Bicknell had only one question: Was Pate aware that his well water was contaminated with the [carcinogen 1,4-dioxane](#)? Although Pate's family had been renting the home for over two years, they were not aware of the chemical, and had been using the water for all their day-to-day needs: cooking, bathing, making infant formula.

“GEA provides the highest quality, lowest cost project management and leveraged consulting services worldwide...”
Dan Bicknell's day job.
[geallc.org](#)

1,4-Dioxane

Health numbers*	Regulatory advisory numbers**
1000000	1000000
100000	100000
10000	10000
1000	1000
100	100
10	10
1	1

There are complex relationships between regulatory levels and levels correlated with health effects.
[epa.gov](#)

COMMENT

Just like that, Pate found himself trying to move his wife and three young children out of their house—no matter what the cost. “Since I’ve been told this, [it’s like I’m on high alert](#), waiting for something to happen, where I’ve got to rush someone to the hospital,” Pate said. No one from the state had knocked on Pate’s door since the family began renting the home. His well water was significantly below Michigan’s then-groundwater cleanup standard for 1,4-dioxane, so there was technically no requirement for the state to do so. On the other hand, the well water measured significantly higher than what was recommended at the federal level by the U.S. [Environmental Protection Agency \(EPA\)](#). How could such a large difference exist between federal and state standards?

The news breaks a story and you get water: Family with poisoned well retains attorney

“I’m just really upset that people can know about something and harm children. I don’t understand it.”

[mlive.com](#)

Next: Beginning in 1984... >

Fig. 1. Screenshot of a case study on Gala. Pages are listed in the table of contents on the left-hand side of the screen, and the narrative text is broken into cards (off-white boxes behind text). Links to Edgenotes appear as green underlined text within the cards, and Edgenotes appear on the right side of the screen.

and embedded tools from trusted providers. The number of embedded tools that Gala supports has grown over time, and these have been important for progressively adding interactivity to the case studies. Tools developed by the Knight Lab at Northwestern University were some of the earliest to be integrated into Gala, and they have been used to create timelines of events [36] and illustrations of landscape change [37]. Later cases integrated interactive maps [38] and an R Shiny app that allows users to explore invasive species data [39]. Edgenotes can be either curated or produced by the case authors. In some instances, case authors have contributed photos or videos from their research travels abroad. For example, one ambitious student author with no previous video production experience recorded her journey through Addis Ababa to trace the city’s wastewater and sewage treatment systems and later edited the footage to produce a set of engaging videos to accompany the case [40]. Although Edgenotes have been noted as a positive component during informal conversations with case users, they were initially underused. Student feedback revealed that Edgenotes looked too much like static textbook images, and they were redesigned to better signal them as interactive components (see Fig. 2).

Many cases also include *supplementary media*. Supplementary media began as audio podcasts but grew to encompass additional media forms. Podcasts have their own dedicated pages within the cases and include transcripts for accessibility. They are typically coproduced by the case authors and MSC staff, and they engage the perspectives of decision makers, specialists, and/or citizens on the sustainability problem in question. Sometimes they explore a critical lens that is not well represented in the narrative [41] or

a set of emerging issues and skills that are not addressed by standard methods for sustainability problem analysis and decision-making [42].

Each case also includes at least one *engaged learning exercise* that teaches critical skills and/or helps users to analyze the case. In comparison to business cases, which typically employ a group discussion as the preferred analysis tool, case studies on Gala use a wide variety of activities that employ active learning strategies. Some case authors have been especially imaginative, such as creating their own online game to illustrate the tensions and tradeoffs inherent in palm oil agriculture [43]. Typically, the engaged learning exercise appears at the end of the case, but some cases intersperse exercises throughout the narrative [44], [45].

A *teaching guide* completes the pedagogical package and is available for most cases at the bottom of the cover page. To alleviate concern from some instructors about supplying answers to students in the teaching guides, only basic information about learning objectives, audience, and teaching plan are included in the online version. Full versions are available upon request by emailing the Gala team, and not the case author(s).

C. Features

1) *Collaborative Features*: Gala was envisioned to facilitate collaboration and exchange not only among classmates but also between classes, and between students and nonuniversity actors such as practitioners. Three main features on Gala enable such collaboration: 1) the discussion forum; 2) Caselog; and 3) the author tools. The in-line *discussion forum* allows readers to

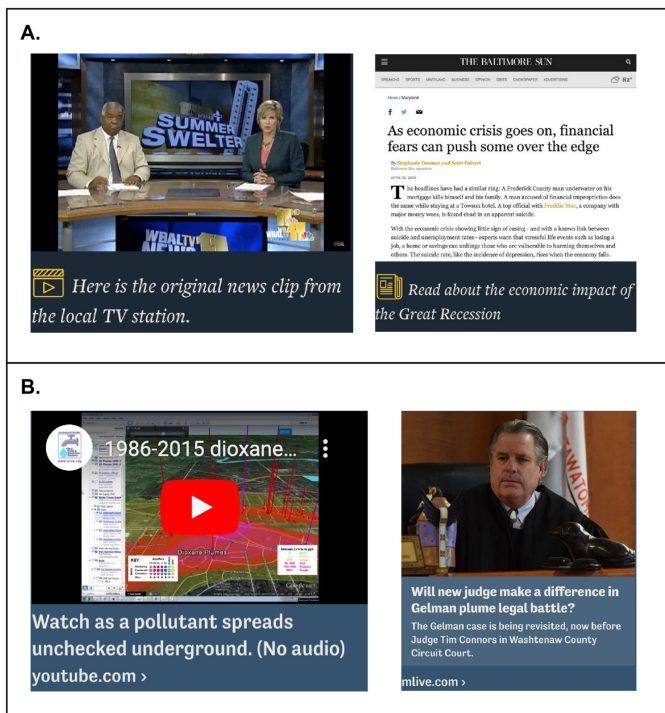


Fig. 2. Evolution of Edgenotes on Gala. (a) Original Edgenote design for videos (left) and links to news articles (right). (b) Redesigned Edgenotes for videos (left) and links to news articles (right).

comment on case text by highlighting the relevant text and clicking “Respond.” Subsequent users can then offer additional comments in the same thread. In addition to fostering productive discussion, this feature allows users to instantly provide an update to some aspect of the case or supply primary documents as attachments or links. *Caselog* builds on the software architecture of the discussion forum and is intended as a place for instructors to record how they used a case, to record the results of case deployment, and to exchange teaching tips and insights with other instructors. The *author tools* enable any user to create, post, and share a case study. When Gala first launched, completed cases had to be manually uploaded to the platform, piece by piece, by MSC staff. After uploading a case, corrections and clarifications to the Edgenotes and narrative text required multiple email exchanges with the case team. This laborious process prompted us to create the author tools, which were introduced in June 2018 and had the salutary effect of increasing the accessibility and inclusivity of the platform.

Following the opening of Gala to a global community, *libraries* were created to house case collections originating from different sources. Branded libraries are reserved for MSC and institutional partners, as a signal that the case materials undergo a higher level of scrutiny before publication and therefore warrant greater trust. The MSC library is currently the largest branded library on Gala. The unbranded Shared Cases library was created in conjunction with the author tools to house user-contributed case studies. Any cases created with the author tools are automatically added to this library, and they can be deployed in the same manner as cases from branded libraries (see the next section). It is also possible to transfer cases from the Shared

Cases library to a branded library; this can happen when a shared case is deemed to be of sufficiently high quality, and it fits within the scope and goals of the branded library.

Gala also facilitates inclusivity by supporting multiple languages and accessibility features. At the time of writing, 78 languages in addition to English were available to users for case creation or translation, and cases have been translated into French, Spanish, and Mandarin from English. The platform is also compatible with mobile devices and was designed with best practices for accessibility in mind. For example, Gala was frequently tested with a screen reader during its development.

2) *Pedagogical Features*: Because case studies are, by nature, teaching tools, it was necessary to incorporate features that support robust pedagogy, including practice (deployment) and assessment. A case study can be deployed through either of two avenues. Because the University of Michigan uses the Canvas LMS (Instructure) to manage its courses, we prioritized the integration of Gala as a tool provider for Canvas [46], and instructors can deploy a case from the Canvas LMS. Alternatively, an instructor can deploy a case directly from Gala by clicking “Deploy this Case” on the case’s cover page. Deploying a case from Gala creates a private study group with an in-line discussion forum specifically for that group. In addition, by using the option to deploy from Gala, the instructor can generate a customized pre- and post-test for the case study, along with a magic link that can be distributed to learners. A magic link is an authenticated URL that directs the user to Gala and adds them to the private study group after they sign in; it removes friction for the user in accessing the correct material. Currently, the pre- and post-tests are the only assessment feature available directly on Gala, and they are only accessible if an instructor deploys a case from Gala. Pre- and post-tests support multiple choice and short answer questions. Multiple-choice responses are automatically graded by Gala, and instructors receive a report detailing each student’s performance, along with their responses to short answer questions.

IV. EVALUATION

Evaluation efforts for Gala first focused on collecting user feedback for iterative improvement of platform features and careful tracking of the platform’s use. Later efforts began to explore the nuances of how different students interact with Gala. In the following, we describe Gala’s growth to date and a pilot study that revealed differences in how graduate versus undergraduate students use Gala.

A. Growth in Platform Use

Because little marketing has historically been done about the platform, Gala’s user base has primarily grown by word of mouth. Originally, Gala required all users to create a free account to view cases in full, but in 2020, this was changed to make the platform more accessible to casual readers, such that accounts are now only required to create a case, deploy a case, or leave comments in the in-line discussion forum. (Deploying and accessing a case through Canvas automatically creates an

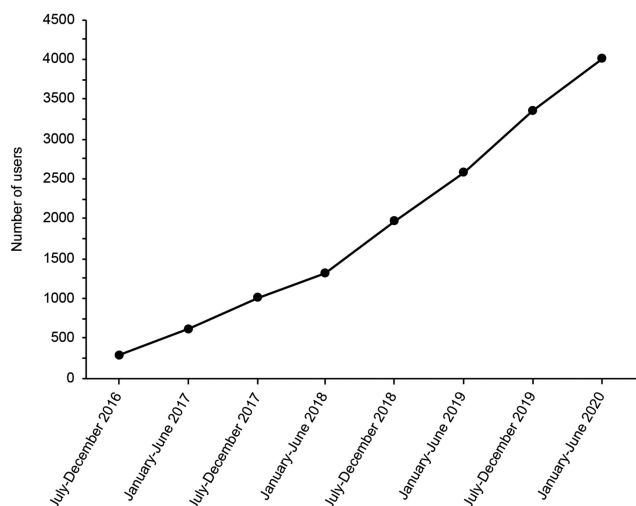


Fig. 3. Cumulative number of users, based on user account creation, since data began to be collected by Gala.

account for the user, which reduces confusion for student users by requiring them to only sign in once with Canvas.) Essentially, accounts are now required only for creative and instructional activities, in order to maintain accountability for user behavior and to enable assessment. However, this early inclination to enforce account creation had the fortuitous effect of allowing us to be able to track account creation—and thereby growth of the user base—over time.

The total number of Gala users has steadily increased, averaging just over 500 new accounts every 6 months (see Fig. 3). Notably, new account creation roughly doubled between the January–June 2018 and July–December 2018 time periods. This likely resulted from greater access to the platform following the launch of the author tools feature in June 2018 and from increasing visibility that led to increased teaching with case studies in university classrooms.

Case studies have been continuously produced since late 2015; however, tracking of cases on Gala did not begin until the latter half of 2017. The platform automatically collects metadata that can be used to determine the pace of case creation over time, including case title and publication date. Publishing a case on Gala makes the case visible and accessible to all platform users while reserving editing permissions for the case authors. Fig. 4 shows the number of published cases on Gala between July 2017 and June 2020. The total number of case studies grew quickly after the launch of the author tools in June 2018, underscoring the importance of giving users the freedom to create their own content. The following semester, two different instructors on the University of Michigan campus assigned students to write case studies and publish them on Gala in lieu of the traditional term paper, an innovation that would not have been possible without the author’s tools. These assignments were the main sources of additions to the Shared Cases library in 2018. Since 2018, the number of published case studies has grown incrementally as new users have contributed to the Shared Cases library, and case studies intended for the MSC library have been completed.

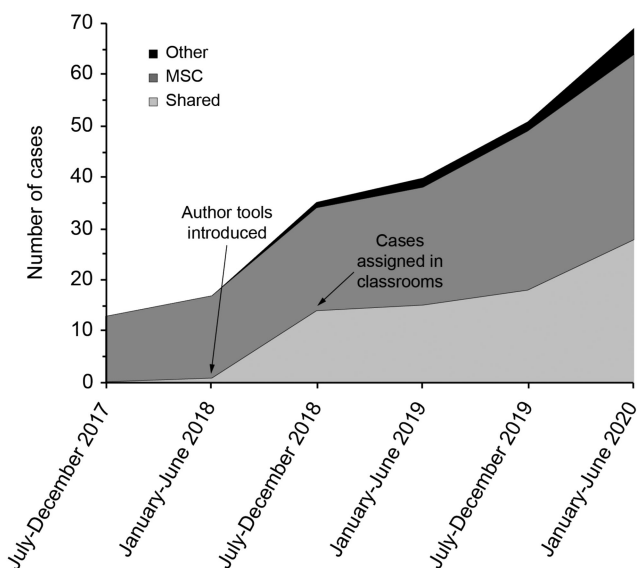


Fig. 4. Growth of published cases by the library on Gala between July 2017 and June 2020. “Other” refers to non-MSB branded libraries. Numbers do not include unpublished cases, some of which are complete and are being used in classrooms. Authors have the option to leave case studies unpublished in order to keep them accessible only to a select group who receive a deployment link from the author or teaching team. Most of the 13 MSC case studies in July–December 2017 time block existed prior to July 2017, but platform metadata only began to be collected in the latter half of 2017.

B. Case Component Usage

A pilot study was conducted in 2017, shortly after the Edgnotes were redesigned, to explore how students use the various case components and to gather feedback about Gala. The study centered on the case “Dioxane Plume Pollution” [47], which describes the history of a contaminated aquifer in Ann Arbor, MI, USA, and decision-making by local, state, and federal stakeholders about how to manage the problem. Students learn about the slow spread of a chemical plume of 1,4-dioxane, a likely human carcinogen, and the policies in place for cleanup. As an engaged learning exercise, students participate in an in-class mock town hall in which they role play different stakeholders to learn how to identify diverse challenges to public health and critical information gaps that impede the resolution of the issue.

We deployed a survey as the first step in understanding student preferences about case design and which case components students use most. Results from the survey are intended to aid in adapting the case to fit college students’ needs and to improve the design of case studies for more effective student learning experiences. As this was an early pilot study, we had little pre-existing information about how users would interact with Gala when we distributed the survey, and so we are unable to control for differences in instructor expectations and student comfort with multimedia interfaces.

1) *Methods and Results:* The case study “Dioxane Plume Pollution” was taught concurrently in one undergraduate and one graduate course during the Winter 2017 semester at the University of Michigan. After finishing the case in class, students received a Qualtrics survey consisting of Likert-type and

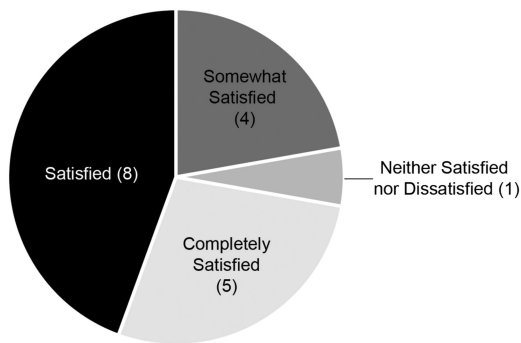


Fig. 5. Student satisfaction with the case study "Dioxane Plume Pollution."

open-ended questions, which asked about their interactions with the case content, how and whether it helped them to learn, and what they liked or did not like about the case. Eighteen students, ten undergraduate and eight graduate, completed the survey. The undergraduate class enrolled 37 students, and the graduate class enrolled 18 students, resulting in an overall response rate of 32.7%. (This is somewhat low but may be explained by the fact that no incentive was offered to students for participating.) All graduate-level respondents were pursuing master's degrees.

Twelve respondents identified themselves as female, and six identified themselves as male. Most respondents ($n = 15$) were of traditional college age, ranging from 18 to 26 years. Fourteen respondents identified as white, two identified as Asian, one identified as both Asian and white, and one identified as multiracial. Four respondents indicated that they are first-generation college students. For 12 respondents, this was their first experience using a case study in a classroom setting. The remaining six students all had prior experience using a case study in another class, with three of those students having previously used another MSC.

Overall, students reported feeling satisfied with the case study. Seventeen students found the case somewhat satisfying to completely satisfying (see Fig. 5). Responses to open-ended questions indicated that students ($n = 4$) liked the case narrative because it challenged them to think beyond ecological concerns by examining the issue from multiple stakeholder perspectives. One participant wrote that "it came from many different angles on the same issue. You could go down many different thought paradigms depending on what stakeholder you were given." The Edgenotes and podcast allowed them to comprehend the different stakeholder perspectives. For example, when asked what they liked best about the multimedia Edgenotes, one participant cited "[m]any different perspectives and it was cool that this case study brought them all together." Another liked that "[i]t had a lot of different information so you could find exactly what you were looking for." Conversely, some students ($n = 3$) expressed that there were too many Edgenotes and that they did not know which ones were required to be read. In addition, some students ($n = 3$) found it hard to pay attention or keep track of who was talking during the podcast because there was no visual aid.

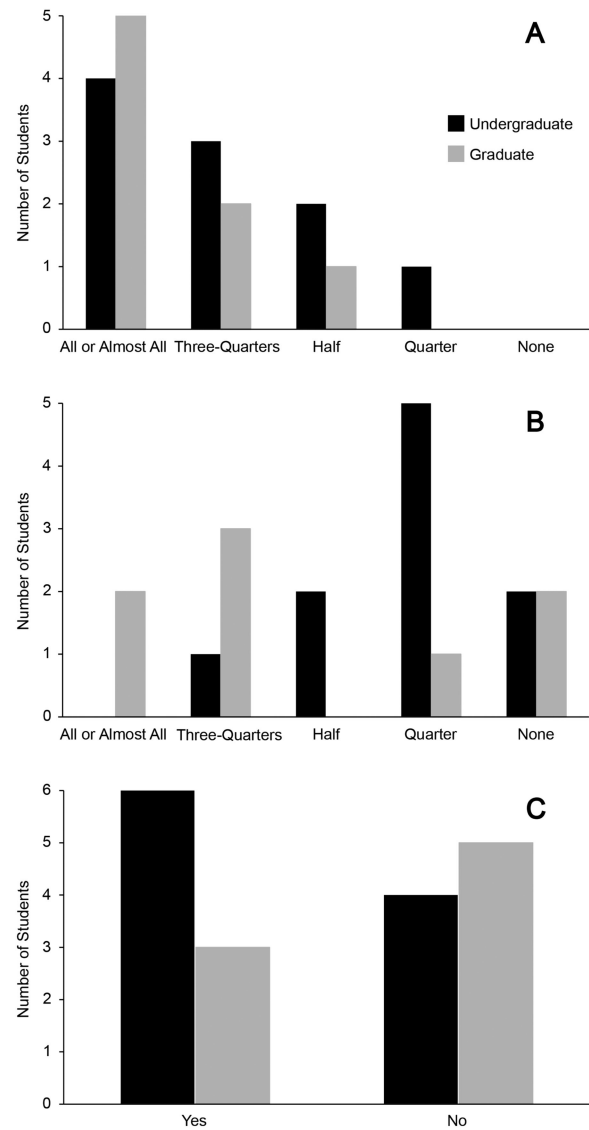


Fig. 6. Student use of case components. (a) Amount of narrative read. (b) Number of Edgenotes clicked. (c) Number of students who listened to the podcast.

Further questions inquired about students' self-reported use of the various content-delivery modes within the case: the narrative, Edgenotes, and podcast. Discernible trends in case component use could only be identified for undergraduate/graduate status, and not for race, gender, or other demographic variables. Among the three case components, students made the greatest use of the narrative, with 14 students reading three-quarters or more (see Fig. 6). Of the other four students, three read half of the narrative, and one read a quarter. Narrative use was similar between undergraduate and graduate students: Both groups had seven students that read three-quarters or more of the narrative. Students used the Edgenotes less than the narrative. About 12 students clicked on a quarter or less of the Edgenotes, and four of those 12 clicked on none. Undergraduate students clicked less frequently, with nine students clicking on half or less. Five of the graduate students

clicked on three-quarters or more, and only three clicked on less than half. However, these numbers may undercount engagement with the Edgenotes because it was discovered in hindsight that the survey lacked an explicit definition of Edgenotes. The four students that did not click on any Edgenotes expressed that they did not understand what Edgenotes were when asked why they did not click on them. This confusion could have caused the students to respond with “not clicked on” even if they did click. Finally, nine students listened to the podcast. A higher proportion of undergraduate students (60%) listened to the podcast than graduate students (38%).

2) *Discussion:* Although it is difficult to draw firm conclusions from a pilot study with small sample size, our survey results nonetheless provide important insights about patterns of user interaction with Gala and provide meaningful, actionable feedback. Survey results pertaining to satisfaction are generally consistent with Mayer’s principles of multimedia design [48]–[50], which articulate best practices for helping learners cognitively process multimedia. The high satisfaction levels (see Fig. 5) might plausibly be the result of the platform following several key principles.

- 1) Gala conforms to the coherence principle of excluding extraneous material by only including a narrative that summarizes the key points of the story being told.
- 2) Gala applies the spatial contiguity principles of presenting on-screen words and corresponding graphics together, such as providing the map of the 2011 expanded dioxane plume prohibition zone alongside the corresponding text.
- 3) Gala incorporates the segmenting principle of smaller, user-paced sections into the structure of the case by dividing the narrative into 11 distinct pages on specific topics related to the dioxane plume.

Students’ critical comments point to design choices that deviate from Mayer’s principles. Confusion surrounding which Edgenotes were required to view suggests a misuse of the signaling principle. Using green underlined text to signal an associated Edgenote may indicate to the student that engaging with the Edgenotes is required. Throughout their education, students have experienced the use of underlined words in textbooks to indicate key information. These repetitive experiences to focus their attention on underlined words may transfer to the Edgenotes, therefore causing confusion about whether Edgenotes are essential for understanding the whole case or are intended for learners to explore at their discretion.

Differences in case component usage may reflect the disparate application of surface and deep learning strategies by undergraduate and graduate students. Surface learning focuses on reproducing rote learned material and is associated with ineffective or temporary learning outcomes [51], [52]. Deep learning focuses on active involvement in the learning process to fully understand complex material, though there is debate over the correlation between deep learning and academic performance [53], [54]. One study that investigated learning strategies used by undergraduate and graduate medical students found that graduate students were more likely to adopt a deep learning approach compared to undergraduate students [55].

In our study, graduate students used the Edgenotes more than undergraduates did [see Fig. 6(b)], which may indicate the use of the deep learning strategy to fully comprehend the case.

Using a surface learning strategy may reflect a student’s disinterest in the material or a perceived high workload in their learning environment. Floyd *et al.* [56] found that students used surface learning strategies when they attributed a low value to a course, suggesting that deep learning strategies occur when students are engaged and the perceived value of the course is high. Litmanen *et al.* [57] suggested that student lack of interest arises from a high perceived workload for the class. Therefore, students that were overwhelmed were more likely to use surface approaches when learning. For this study, lower use of case components could have resulted from the adoption of a surface learning strategy, driven by the perception of a high workload due to the presence of Edgenotes and a podcast, which are not typical of a conventional case study or class reading. A deep learning strategy may be more appropriate for Gala case studies, which challenge students to work with complex, real-world problems. Hence, we propose that active engagement with all case components is needed for a student to develop an in-depth understanding of the problem and suggest constructive solutions.

With regard to instructors, no data were collected about their experience with Gala when teaching “Dioxane Plume Pollution” because the survey was designed to target students. However, testimonials and informal conversations with instructors who have used Gala in other settings provide some indication of the platform’s pedagogical value and challenges from their perspective. One of the instructors who assigned case studies instead of term papers found that Gala and the case study format prompted students to take on a more curious and scholarly role when synthesizing their research [58]. The same instructor commented that the final products were more fun to grade [59]. Other instructors have commented that case use is valuable for students because it connects pressing issues and changes in the built and natural environment with what they learn in the classroom [60]. In addition, instructors mentioned that using decision-based learning tools such as case studies brings the experience of sustainability students in line with that of students from other professional fields (e.g., law, business, and medicine). On the other hand, instructors have found it inconvenient to have to collect student submissions using a secondary tool such as a conventional LMS [61].

Overall, results from our pilot study provide salient insight into how undergraduate and graduate students interact with a Gala case, and how case design can be changed to improve the student experience. Many elements of Gala’s design and case study presentation were well received by students. However, several comments suggest fruitful areas for improvement, especially with regard to nontextual case components. Edgenotes may need to be indicated in a different way or perhaps Gala could incorporate a statement that Edgenotes are present for additional learning support. While podcasts are by nature auditory material, visual aids could be provided by adding photos and links to the podcast page. These adjustments could help increase student

satisfaction and engagement with multimedia content delivery modes. Students may also benefit from specific guidance about how to engage with a Gala case, so that they are more likely to employ a deep learning strategy.

V. FUTURE DIRECTIONS

Promising results from evaluation efforts thus far are driving improvements to Gala and providing important direction for future case production, teaching, interactivity, and assessment. In the following, we discuss a number of growth areas for Gala that are in progress.

A. Platform Redesign

Continued feedback from users through formal and informal channels has highlighted opportunities to create more intuitive workflows for finding, making, and deploying cases. Thus, a redesign of Gala's landing page is currently underway. We are also working with campus partners to curate and create case studies in a Coursera MasterTrack Certificate curriculum entitled "Sustainability and Development: Beyond the United Nations' Sustainable Development Goals (SDGs)." This work introduces possibilities for future platform integration with other learning environments, and for indications on Gala of which cases address individual SDGs or broader sustainability competencies.

B. Expansion of User Base

Recent outreach and communications efforts, such as a regular newsletter for platform users and increased social media presence, have helped to sustain and increase the number of case makers, learners, and teachers using Gala. This is a positive outcome for Gala, though an increasing user base brings with it increased challenges for monitoring content and protecting intellectual property rights, for both case authors and those whose work may be used within Edgenotes. To address these concerns, we are developing a terms of use agreement that will govern user behavior and responsibilities going forward.

C. Interactive Elements

Structuring the case studies as text augmented with multimedia elements has provided a useful basis for thinking about ways to increase interactivity and engagement, with many ideas coming from the platform's users. For example, through a partnership funded by the Midwest Big Data Hub, new case authors are adapting existing instructional material for Gala that helps students learn to formulate a hypothesis and test it using data. Data access and exploration are enabled through an R Shiny app that is more intuitively embedded in Gala than has previously been done. The funding is also enabling the creation of student fellowships targeting minoritized learners to work with faculty and student authors of existing Gala cases. Other case authors are building a new case around the idea of sound in the environment and have extensively used audio clips to build a sensory experience.

D. Assessment

The full range of ways that Gala can be used has not been fully explored, and future assessment will involve further investigation of current case deployments and innovative new applications. For example, Gala collects log data related to how and when users interact with the platform. These data have so far not been utilized, but they are potentially a rich source of information about how the platform is working and for whom. We are currently exploring how these data could be used for rigorous assessment while respecting privacy concerns and ethical boundaries.

VI. CONCLUSION

Gala has proven to be a popular, adaptable tool for teaching sustainability science. Feedback from students and faculty about the platform and many of the case studies have been generally positive. In addition, though case studies have a long history of successful use as text-based hard copy and digital pdf pedagogical tools, the choice to host case studies on an interactive online platform has brought many benefits. Sustainability issues tend to evolve rapidly, and the platform allows for richer contextualization of the issues, with more timely and nimble updates to curricular materials compared to other formats. Gala also enables close integration of text, media, and external web-based tools, thus helping to meet the growing demand for training of data-savvy sustainability practitioners who are able to successfully navigate complex and rapidly changing issues with diverse stakeholders. Moreover, Gala's open-source code allows novice and experienced programmers to contribute ideas and grow their skills. Interactive features such as the discussion forum connect learners from different backgrounds across the globe, enabling diverse and inclusive insights into shared sustainability problems. Finally, the open-access nature of Gala has made sustainability learning available to anyone with an internet connection, including on mobile devices, and opened up content creation to anyone with a compelling story to tell.

Assessment of Gala and its impacts on teaching and learning have been priorities since the platform's beginning, and it remains an important area of work. The exploratory pilot study reported here reveals clear differences in how undergraduate and graduate students interacted with the platform. These results form a basis for further investigation, especially into how case design can best engage different demographic groups. Follow-up studies will include larger and more diverse samples, ideally in various geographical and institutional contexts, as well as other cases. Thus, more targeted assessment with statistically robust sample sizes will enable us to confirm whether case component usage patterns and the reasons we suggest for them are valid and generalizable.

In addition, at the time of writing, the COVID-19 pandemic event is unfolding across the globe. As one consequence, most higher education learnings moved online in 2020, presenting an unforeseen opportunity to rapidly test Gala at scale. Gala was designed to support a mixture of face-to-face and online learning, and so the sudden shift to virtual and hybrid

environments has prompted both experimentation and new thinking about how Gala might be assessed. It will be months or years before the effects of the sudden switch to online learning are fully known. However, it is now clearer than ever that the future of higher education must include a robust online component, and tools like Gala that enable synchronous and asynchronous collaboration for open-access content delivery and open-source, egalitarian content creation will be increasingly in demand.

APPENDIX

Dioxane Plume Pollution: Case User Feedback Survey

- 1) *Is this the first time that you have experienced a case study in a classroom setting?*

Response options: Yes, this is my first experience with case studies in a classroom setting; No, I have experienced case studies in previous classes; Not sure/I don't remember.

If "No, I have experienced case studies in previous classes" is selected, display Question 2.

- 2) *Was it a Michigan Sustainability Case (MSC)? Note: MSCs are modular multimedia sustainability case studies developed through partnerships with practitioners, teachers, and students that present actual experiences or experiences inspired by real circumstances of key "decision makers" through a digital platform. Each MSC is accompanied by the case narrative, multimedia "Edgenotes," a podcast, and an interactive learning exercise.*

Response options: Yes; No.

If "Yes" is selected, display Question 3.

- 3) *How would you rate your previous experience with MSC?*

Response options: Completely satisfied; Satisfied; Somewhat satisfied; Neither satisfied nor dissatisfied; Somewhat dissatisfied; Dissatisfied; Completely dissatisfied.

- 4) *How much of the case narrative did you read?*

Response options: I read all or almost all of the case narrative; I read about three-quarters of the case narrative; I read about half of the case narrative; I read about a quarter of the case narrative; I didn't read the case narrative.

If "I didn't read the case narrative" is selected, skip to Question 8.

- 5) *What did you like best about the case narrative?*

(open-ended response)

- 6) *What did you like least about the case narrative?*

(open-ended response)

- 7) *To what extent do you agree or disagree with the following statements about how the case is written?*

The language used in the case is straightforward and easy to understand.

The case narrative flows in a logical manner.

The case narrative is interesting.

The case narrative explores the groundwater pollution issue in-depth.

The case narrative provides a diversity of perspectives of the different stakeholders involved in the Gelman case.

Response options: Strongly agree; Agree; Somewhat agree; Neither agree nor disagree; Somewhat disagree; Disagree; Strongly disagree.

- 8) *How many of the multimedia Edgenotes did you click on while reading through the case?*

Response options: I clicked on all or almost all of the multimedia Edgenotes; I clicked on about three-quarters of the multimedia Edgenotes; I clicked on about half of the multimedia Edgenotes; I clicked on about a quarter of the multimedia Edgenotes; I did not click on any of the Edgenotes.

If "I did not click on any of the Edgenotes" is selected, display Question 9 and then skip to Question 14.

- 9) *Briefly explain why you decided not to click on the multimedia Edgenotes.*

(open-ended response)

- 10) *What did you like best about the multimedia Edgenotes?*

(open-ended response)

- 11) *What did you like least about the multimedia Edgenotes?*

(open-ended response)

- 12) *What style of multimedia Edgenote did you prefer?*

Response options: Video; Audio; Primary source (peer-reviewed articles and reports); Text (websites, periodicals, etc.); Images and figures; Other.

- 13) *To what extent do you agree or disagree with the following statements about the multimedia Edgenotes?*

The multimedia Edgenotes were presented in an accessible, intuitive way.

The multimedia Edgenotes provided helpful, complementary information.

The multimedia Edgenotes helped me to better understand certain elements of the case.

Studying the case online with multimedia elements was better than reading a printed version.

The number of multimedia Edgenotes provided was distracting.

Response options: Strongly agree; Agree; Somewhat agree; Neither agree nor disagree; Somewhat disagree; Disagree; Strongly disagree.

- 14) *I listened to the Podcast.*

Response options: Yes; No.

If "No" is selected, display Question 15 and then skip to Question 19.

- 15) *Briefly explain why you decided not to listen to the Podcast.*

(open-ended response)

- 16) *What did you like best about the Podcast?*

(open-ended response)

- 17) *What did you like least about the Podcast?*

(open-ended response)

- 18) *To what extent do you agree or disagree with the following statements about the Podcast?*

The Podcast was easy to understand.

The Podcast was the right length.

The Podcast held my attention for its entire length.

The Podcast provided helpful, complementary information.

The Podcast helped me to better understand the pros and cons of applying for Superfund designation.

Response options: Strongly agree; Agree; Somewhat agree; Neither agree nor disagree; Somewhat disagree; Disagree; Strongly disagree.

19) *What are the main strengths of this case?*
(open-ended response)

20) *How could this case be improved?*
(open-ended response)

21) *To what extent do you agree with the following statements about your learning experience with this case?*

I felt more motivated to learn.

The learning process was more engaging than usual.

The pace of learning during this process was in my control.

The case provided real world examples that grounded concepts introduced in class.

The case helped me to better appreciate the complexity of the issue studied by providing different perspectives and background information on the issue.

Response options: Strongly agree; Agree; Somewhat agree; Neither agree nor disagree; Somewhat disagree; Disagree; Strongly disagree.

22) *Please rate your overall satisfaction with this case.*

Response options: Completely satisfied; Satisfied; Somewhat satisfied; Neither satisfied nor dissatisfied; Somewhat dissatisfied; Dissatisfied; Completely dissatisfied.

23) *What is your age?*

Response options: <18; 18–21; 22–26; 27–30; 31–34; >34.

24) *Please select your current standing as a student:*

Response options: Undergraduate student; Graduate student—Masters; Graduate student—PhD; Other (please specify).

25) *Do you have any of the following disabilities or other health impairments?*

Response options: Learning difficulties (including dyspraxia); Dyslexia; ADHD/ADD; Speech impairment; Visual impairment; Hearing impairment; Other (please specify).

26) *What is your gender identity?*

Response options: Male; Female; Other (describe); Decline to respond.

27) *Are you an international student?*

Response options: Yes; No.

28) *Do you identify as Hispanic or Latino/a?*

Response options: Yes; No.

29) *What is your race?*

Response options: Asian; Black or African American; Hawaiian or Pacific Islander; American Indian or Native American; White; Other (describe); Decline to respond.

30) *Are you a veteran?*

Response options: Yes; No.

31) *Do you consider yourself a nontraditional student?*

Response options: Yes (please specify why); No.

32) *What is the highest degree obtained by either one of your parents?*

Response options: Graduate or professional degree (PhD, masters, MD, etc.); Bachelor's degree; Associate's degree; High school diploma; Did not complete high school.

33) *What is your parents' annual household income?*

Response options: <\$10,000; \$10,000–\$19,999; \$20,000–\$29,999; \$30,000–\$39,999; \$40,000–\$49,999; \$50,000–\$59,999; \$60,000–\$69,999; \$70,000–\$79,999; \$80,000–\$89,999; \$90,000–\$99,999; \$100,000–\$109,999; \$110,000–\$119,999; \$120,000–\$129,999; \$130,000–\$139,999; \$140,000–\$149,999; >\$150,000.

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