COLLABORATIVE DESIGN REASONING IN A LARGE INTERDISCIPLINARY LEARNING TOOL DESIGN PROJECT

Feiya Luo, Pavlo "Pasha" Antonenko, Natercia Valle, Emily Sessa, Gordon Burleigh, Lorena Endara, Stuart McDaniel, Sarah Carey, & E. Christine Davis, *University of Florida*

This design case discusses the complex collaborative design reasoning processes involved in developing an online interactive learning tool for learners of all ages to explore and understand the role of flagellate plants in our society. The learning tool consists of a main website (the *Voyager*) and an interactive, dynamic map of the evolutionary relationships between thousands of flagellate plant species (the customized *OneZoom* web application). The design and development of this innovative learning tool required expertise in collaborative design, design reasoning, project management, theories of learning and instructional strategies, software development, and web usability. Collaboration platforms used by the project team involved *GitHub* and *Slack*. Domain knowledge needed to complete the project included botany (flagellate plants), web programming (*Python* and *JavaScript)*, and database management (*MySQL*). The project included a team of international experts who negotiated design strategies and solutions over the course of a year and produced and improved prototypes until converging on the final product. This article explains the challenges faced during these processes and presents solutions and lessons learned from this experience.

Feiya Luo is a Ph.D. candidate in Educational Technology at the University of Florida. Her research interests include using innovative technologies in integrated STEM.

Pavlo "Pasha" Antonenko is an Associate Professor in Educational Technology at the University of Florida.

Natercia Valle is a Ph.D. candidate in Educational Technology at the University of Florida.

Emily Sessa is an Associate Professor in Biology at the University of Florida.

Gordon Burleigh is an Associate Professor in Biology at the University of Florida.

Lorena Endara is a Post-Doctoral researcher in Biology at the University of Florida.

Stuart McDaniel is an Associate Professor in Biology at the University of Florida.

Sarah Carey is a Ph.D. candidate in Biology at the University of Florida.

E. Christine Davis is a Senior Lecturer in Biology at the University of Florida.

INTRODUCTION

The design case discussed here represents the work of a large team of interdisciplinary scholars, designers, and software development consultants aimed at creating an innovative online technology that underscores the role of flagellate plants in our society. For the first 300 million years following plants' invasion of land, Earth's terrestrial flora consisted entirely of flagellate plants. These include the bryophytes, lycophytes, ferns, and gymnosperms, and today, these lineages comprise approximately 30,000 species. During the evolution of these groups, numerous botanical innovations evolved that define plant biodiversity today. Stomata, vascular tissue, roots and leaves, lignified stems with secondary growth, and seeds all evolved first in flagellate plant ancestors. These plants, therefore, hold the keys to understanding early evolution of these critical features. The flagellate plants not only provide a window to innovations of the past, but are represented by vibrant, speciating lineages that contribute substantially to modern global ecology, particularly via contributions to global carbon and nitrogen cycles (Voogt et al., 2015).

Despite their rich evolutionary history and vital roles in almost all ecosystems, flagellate plants are overlooked and understudied relative to the flowering plants, many of whose features can only be understood in the light of flagellate plant evolution. To address this fundamental gap in our understanding of the phylogeny of life, this project was conceptualized to design and develop a set of educational resources and an innovative online technology for learners of all ages and backgrounds. Unfortunately, there is a lack of literature that documents the processes underlying the development of educational tools for learning, particularly when using open source technologies and contexts where software consultants are located in a different country and are not active members of the larger project. This paper describes how this collaboration was accomplished by the first author, who is an educational technologist, with background knowledge in computer programming. It also details the design processes, challenges, and solutions that emerged during the development and software customization phases (Hayek, Teich, Klein, & Grêt-Regamey, 2016).
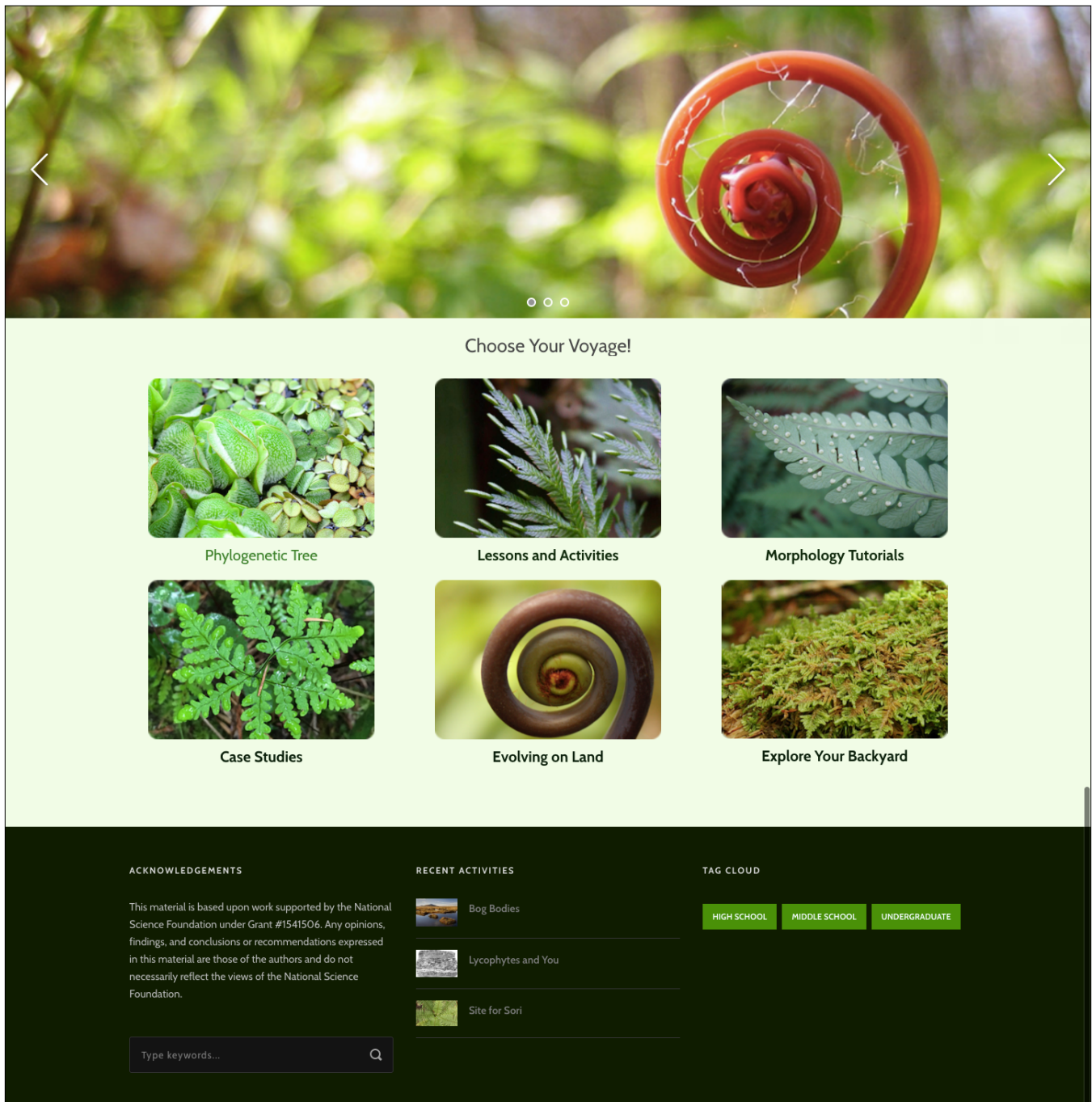

FIGURE 1. The Voyager homepage (used with permission).

Funding for this work was provided by the US National Science Foundation. The project consists of a basic science component—analysis of molecular genetic variation among the 18,000 available flagellate plant species to create a species-level phylogeny, and an education component—that is, design, development, and implementation of educational resources and tools to increase public awareness of the role flagellate plants play in our society. The interactive learning tool discussed in this paper is intended for different age and user groups. Age groups include students in elementary, middle, high school, as well as undergraduate and graduate students. User groups included students, parents (e.g., those who homeschool their children), Botany enthusiasts, and educators (K-12, higher education, and informal). The content housed in this interactive learning tool is appropriate for both formal and informal teaching and learning. For example, an elementary student who is curious about the scientific names of ferns can browse the "Morphology" section of the website; a high school student interested in learning more about the evolutionary relationship of ferns in addition to their science class content may visit the Phylogenetic Tree for more detailed biological traits and characteristics; a college Botany instructor may use the resources and activities provided in the interactive learning tool as course assignments.

This paper describes the collaborative design processes and a series of design decisions involved in developing and integrating the *Voyager* technology (main project website) and an interactive, dynamic map of the evolutionary relationships between thousands of flagellate plant species (the *OneZoom Tree of Life* web application). The *Voyager* (Figure 1) is the core hub for all educational content on flagellate plants produced by the project team. It includes lessons and activities (curriculum modules), morphology tutorials (plant traits and vocabulary), case studies (inquiry-based activities), evolution information (characteristics and adaptations

associated with flagellate plant evolution), and so on. *OneZoom*, on the other hand, is an open-source web application that the team customized to provide a visualization of the *Tree of Life* or the evolutionary relationships between flagellate plants to compliment learning and exploration activities on the *Voyager*.

In addition to the core expertise in the main subject matter (Botany) and educational technology, the design and customization work in this project requires knowledge of both "front-end" (client-side) and "back-end" (server-side) development. Front-end development refers to the design of user interface (such as websites) and often involves manipulating *HTML*, *CSS*, and *JavaScript*. In our project, front-end development includes implementing the *Voyager* tool using *WordPress* and customizing a WordPress theme using HTML and CSS. Back-end development deals with the server and database management, and outputting of information to the users, which requires mastering of *MySQL*, *Python*, C-Panel, and running *command-line* scripts. Back-end development in our work consists primarily of the customization of *OneZoom*, which is an open-source application implemented using *Python, MySQL,* and *Javascript*.

DESIGN COLLABORATIVE

This project brought together subject matter experts (SMEs) in Botany and Education in Southeastern United States and software consultants based in London, UK. The project team consists of nine members. Five are university professors and instructors (one in Educational Technology and four in Botany), three are doctoral research assistants (two in Educational Technology and one in Botany), and one is a post-doctoral student in Botany. Two of the Botany professors and the professor in Educational Technology led the educational and outreach component of the project and oversaw the design and development of the *Voyager* and

STAKEHOLDERS	STAGES					
	INITIATION OF PROJECT *(January 2017)*	*VOYAGER* DESIGN *(February–May 2017)*	*ONEZOOM* SOFTWARE CUSTOMIZATION			DESIGN WRAP-UP *(November–December 2017)*
			VERSION EXPLORATION *(April–May 2017)*	DATA TRANSFORM *(June–July 2017)*	DATA VISUALIZATION *(August–October 2017)*	
SMES (BOTANY)	●	●				●
SMES (EDUCATION)	●	●				●
TECH DEVELOPER	●	●	●	●	●	●
ONEZOOM CONSULTANTS	●			●	●	

TABLE 1. Expertise spectrum of major stakeholders.

OneZoom. While the design of the software was conceptualized by the entire team, and particularly, by the three professors and the students involved in the education component of the project, one educational technologist (first author) was responsible for the technology development. The other members on the team are biology experts, responsible for providing the phylogeny data used in *OneZoom* to visualize the evolutionary structure of flagellate plants and participated in executive decision-making during the tool design and development processes.

In addition to the nine project members, the original, open-source *OneZoom* software developers based in London served as consultants for the *OneZoom* software customization. Table 1 describes the expertise spectrum of major stakeholders (bulleted areas) throughout the design and development processes.

CONCEPTUAL FRAMEWORK: COLLABORATIVE DESIGN REASONING

To organize project workflow and distribute responsibilities, the team examined common software development frameworks, such as Agile and Scrum. However, in our case, there is only one team member responsible for technology development, and the work involves a high degree of exploration and troubleshooting for someone with limited software engineering background knowledge. In addition, there is no sprint planning, developer collaboration, or iterations like Agile and Scrum frameworks require. Therefore, the team had to search for another framework that fit their condition. The team identified collaborative design as the appropriate framework for the reasons discussed next.

According to Kvan (2000), collaborative design a) should include a clearly defined purpose of the collaboration and interdependencies among team members, b) involves members of different professions contributing their unique knowledge to the design situation. Bringing together different stakeholders can foster new insights, ideas, and designs to the collaborative situation (Arias, Eden, Fischer, Gorman, & Scharff, 2000). For example, in the field of construction, collaborative design has been employed as a framework to guide interdisciplinary projects with the unique expertise of different stakeholders, such as an architect to manage and oversee the project, a structural engineer to ensure the sturdiness of a building, a mechanical engineer to design the mechanical systems in the building, an electrical engineer to route electrical power, and an environmental engineer to ensure compliance with environmental protection guidelines and regulations (Case & Lu, 1999).

On the other hand, design reasoning is conceptualized by Boschman, McKenney, and Voogt (2014) to deal with influences on the design team's interactions. It encompasses a) existing orientations, which refer to stakeholders' skills,
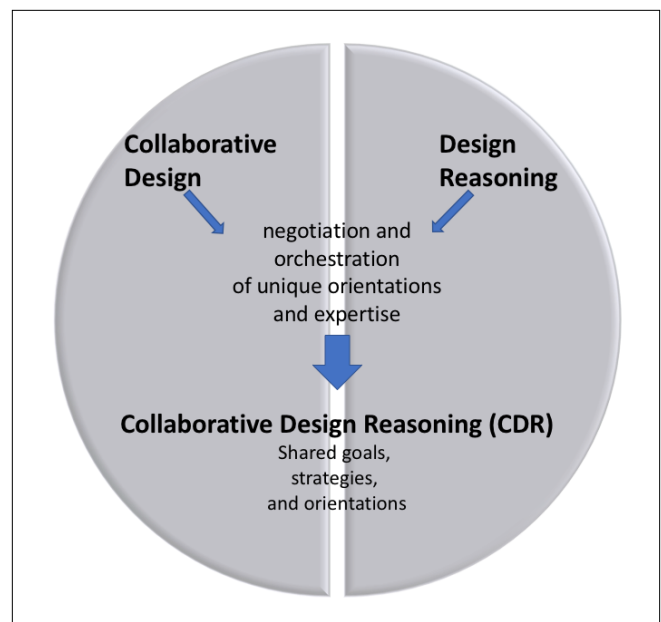

FIGURE 2. Conceptual Framework: Collaborative Design Reasoning.

knowledge, beliefs, and practices; b) external priorities, such as national or institutional policies and expectations, funding, and deadlines; and c) practical concerns, in terms of making the most feasible decisions considering the restraints. Indeed, collaborative design coupled with design reasoning, or collaborative design reasoning (CDR), is an integrative design framework that provides the logical tools that can be used to establish shared goals, communication strategies, and even shared vocabulary given the external constraints, practical concerns, and existing orientations among a large team of experts with unique disciplinary foci (Figure 2).

Designing an online interactive learning tool, for example, requires knowledge, skills, and expertise in the learning content (in our case—Botany), human-computer interaction, instructional design, software design and development, and so on (Nowak & Pautasso, 2011). Experts in each of these domains typically use theoretical frameworks and methodological strategies that do not easily translate between disciplines (i.e., differences in existing orientations). Therefore, the issue of negotiating, establishing and using common views on the problem and solution strategies may be overwhelming. As an example, many interactive learning tool designers and researchers are familiar with cognitive load theory (Sweller, 1988; 2011), which discusses the amount and nature of the cognitive resources expended during a task. This framework proposes three types of cognitive load: extraneous (hinders learning), germane (helps learning), and intrinsic (complexity of learning content). Thus, cognitive load is often conceptualized by educational technologists as a multi-faceted concept that does not always produce a negative connotation, as in the case with germane load,

that actually promotes effective learning by appropriately challenging the learner's cognitive system.

On the other hand, human-computer interaction and ergonomics design and scholarship have a different existing orientation in that they employ the term "mental workload" to describe what educational researchers would refer to as "extraneous load." In the mental workload orientation, cognitive effort is a negative construct, typically caused by a design element that needs revising. Given these differences in the theoretical perspectives, these two disciplines approach the measurement of cognitive load using very different approaches. Educational researchers often employ measures that are designed to measure all three types of cognitive load (e.g., Leppink, Paas, Van der Vleuten, Van Gog, & Van Merriënboer, 2013), whereas human-computer interaction researchers focus only on the negative aspects of "load", which resulted in the development of such instruments as NASA Task Load Index that focuses on such load dimensions as mental demand, physical demand, temporal demand, perceived performance, perceived effort, and frustration (Hart & Staveland, 1988; Hart, 2006). This example serves to demonstrate that establishing a shared conceptual orientation and shared vocabulary for a project can be a very difficult endeavor—particularly when the experts representing different domains do not possess a shared language for discussing the problem to be solved or the strategies to be negotiated during the design process.

In our work, collaborative design refers to the collective expertise, communication, and effort all members dedicate in order to discuss, set up, and complete project objectives. From a pragmatic perspective, collaborative design reasoning in this project is supported through regular biweekly meetings, face-to-face and online information exchanges before, during and after the design process using email and shared repositories such as Google DriveÔ, videoconferences between the project team and the *OneZoom* consultants in London, and collaboration on *Slack* (cloud-based collaboration tool) and *GitHub* (web-based version control tool for computer code updates) and so on.

In the early design stage of this project, collaborative design took the form of what design researchers referred to as loosely coupled collaboration (Case & Lu, 1999; Kvan, 2000). This meant that active communication and sharing usually happened at the beginning and the end of each problem-solving situation, because collaboration could be very time-consuming, and most team members were involved in multiple projects at the time. The team adopted moderately coupled collaboration only when there were very particular problems that required distinct and intensive expertise input. This form of collaboration emerged in the middle and the late stages when dealing with a number of technical issues (server configuration, troubleshooting database queries, importing flagellate plant data into *OneZoom*) and external

constraints, such as meeting deadlines and finding available tools to be used in the design and development process.

SHARED DESIGN DECISIONS

An important external constraint to the design process was that the funding agency expected the team to address three core components of the *Voyager* system as an instructional platform to facilitate learning (Ertmer & Newby, 2013): a) usability, b) organization of the website, and c) content presentation.

The CDR framework proves useful in guiding the interdisciplinary collaboration necessitated by the external priorities, practical concerns, and existing orientations in this project. For design and development of the *Voyager*, external priorities are user experience and usability (i.e. presenting the most relevant information, clear navigation and content structure, and not overwhelming users); existing orientations are the need for abundant content and the need to follow design principles to present and organize content; practical concerns are to organize the homepage and allow sorting of content based on interest using existing WordPress features. For the customization of *OneZoom*, multiple functionalities, such as linking to database and touch screen, are the external priority whereas the decision over which versions to explore and eventually choose and how it could be timely deployed are the major practical concerns. In addition, CDR also ensures that the team properly addresses domain-specific design elements such as instruction (educational elements), nature of subject matter (botany), and orchestration of existing and new databases (data management. The main design conflicts and decisions that the team converged upon during the CDR process for the *Voyager* and *OneZoom* technologies are described next.

One of the major conflicts that the team encountered around usability was the presentation of content on the *Voyager*. The organization of the subpages, tabs and content on the *Voyager* website was the subject of many CDR discussions, as the team was committed to designing a system that would allow easy structuring of learning materials (for search and sorting purposes) to support scaffolding of the information navigation based on user's existing navigation schemas (Kashihara, Nakaya, & Ota, 2006; Nielsen, 1999). While the initial design idea of the Botany SMEs was to have all content visible on the homepage, the education SME emphasized the importance of enhancing user experience with a simple navigation structure. For example, a learner may be interested in the general definitions of flagellate plants and a visit to the main webpage may suffice; on the other hand, if information on different groups of plants is needed, exploring other subpages and external resources may yield better results, but these resources must be organized in a manner that would make sense to a typical user. This example illustrates the challenge of providing information according

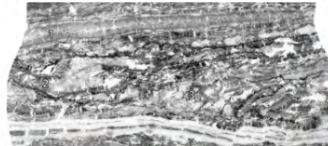**FIGURE 3.** Learning activities with sorting tags (used with permission).

to the needs of learners without overwhelming them or oversimplifying the content. Part of the concern, in this case, is that *Voyager* users are expected to represent different ages, socioeconomic strata, and prior knowledge in Botany.

The negotiation around this conflict started with the educational technology professor presenting to the team instructional design guidelines and human-computer interaction principles. The educational technology professor then proposed that instead of having separate webpages to host activities for different age groups and user groups (many of which would overlap), WordPress' blogging application and its Tag Cloud plugin can be used to host learning activities. Specifically, all activities would appear on one "blog" page using the gallery mode (to show large buttons for each activity, rather than a long list of activity titles), and the Tag Cloud served as the tool for sorting the learning activities in an at-a-glance view. Each activity is tagged with an appropriate

age group (e.g., elementary), and users can sort activities by age group by simply clicking on the appropriate tag (Figure 3). The Botany SMEs consented to the solution after the conversation on ensuring rich content under the proposed navigation structure. Another design solution that the team converged upon once a well-organized system was designed was the inclusion of white space between important chunks of information, a common practice in graphic and web design that promotes coherence (Golombisky & Hagen, 2017).

As a result of preliminary conversations, the team converged on the idea of a "clean" design, providing only the essential, just-in-time information where appropriate (Kester, Lehnen, Van Gerven, & Kirschner, 2006) and straightforward navigation based on the schemas that *Voyager* users would already have. From the user interface design perspective, these decisions are based on visual interface design principles on how

the organization and the structure of the information on a website influence the user experience (Cooper, Reimann, Cronin & Noessel, 2014; Pannafino, 2012). This serves as an example of how design conflicts were resolved by implementing the sorting feature that allowed for housing of extensive Botany content in a way that can help users easily locate what they are looking for.

Another element of usability that can support learners' search and location of information is the use of easily identifiable points of interaction, such as workable links that are responsive to users' actions (e.g., an icon changes color or size as the learner hovers over it). Moreover, extra care is taken to avoid the phenomenon of false affordances (Cooper et al., 2014) in the system, which may make learners think that some outcome will follow when, in fact, the capability for the expected outcome is not built in the system (e.g., click on a picture for additional information when a link to additional information does not exist). Thus, the allocation of interactive elements is parsimonious but strategic.

Following the design framework, the team addressed content presentation by grouping content into six blocks, each with a short caption on the *Voyager* homepage. Other features of content presentation involve a responsive web design feature where the size of the screen expands and shrinks according to the size of the web browser across mobile devices (Shneiderman, Plaisant, Cohen, & Jacobs, 2009), a slight zoom effect of the six blocks when the mouse hovers over to provide enhanced signaling (Van Gog, 2014), a touch screen functionality which offers a more interactive gesture-based approach to navigating and controlling the *OneZoom* tree on touch screens, and user-controlled features such as zoom in and out, resetting of the *OneZoom* tree and so on. Touch-screen interaction affordances are the focus of several CDR discussions in our project because many schools rely on touch-screen devices today (Soltis, Moore, Sessa, Smith, & Soltis, 2018). Particularly in the case of visuospatial tasks such as the exploration of the Tree of Life provided by OneZoom, the characteristics of mobile, touch-screen devices that use touch-gestures and interactive 3D representations can provide important benefits concerning success in visuospatial reasoning and motivation (Zander, Wetzel, & Bertel, 2016).

In terms of the nature of the subject matter, the design accommodated the semiotic elements (Bezemer & Kress, 2008) related to botany and flagellate plants specifically. For example, the green color represents plants in different parts of the *Voyager*. The use of *OneZoom* represents connections of biodiversity, and the importance of tree thinking, an important skill in the life sciences (Halverson, 2011). Tree thinking is reflected in the design of this online interactive learning tool, as well as the learning activities that integrate the use of *Voyager* and *OneZoom* in the project. Finally, only non-flowering plants are included to illustrate concepts or represent icons and decorative design elements because all flagellate plants are flowerless. The team decided to keep the use of metaphors to a minimum to avoid possible misinterpretation of these metaphors by learners from different cultural and ethnical backgrounds. Whenever possible, meanings are specified using illustrative photos and texts.

Importantly, the design of the *Voyager* and the *OneZoom* customization take into consideration of the ever-changing nature of what is being discovered about flagellate plants and their phylogenetic composition. As a result, the system's database is accessible for updates of incoming sets of data on groups and species. *OneZoom* consultants from London developed such affordance to transform Newick files that are used in Botany to store tree relationships among a group of species to a Structured Query Language (SQL) file read by the *OneZoom* data import facility.

DESIGN & DEVELOPMENT PROCESSES

The design and development processes underlying the *Voyager* and *OneZoom* production were the result of extensive CDR negotiations (external priorities, existing orientations, and practical concerns) among subject matter experts, the educational technologist, and software consultants. These processes are detailed next in chronological order.

Initiation of Project (January 2017)

Customization of the open-source *OneZoom* application was perceived by the team as the first and foremost task due to the complexities involved in using Python and SQL code and our team's relative lack of expertise with these technical aspects of software engineering. The team met virtually with the *OneZoom* consultants to communicate the shared vision of customizing *OneZoom* for the specific needs of this project (e.g., the team's exclusive focus on flagellate plants). The team obtained the license and user terms of *OneZoom* and inquired about possible versions of the original software code that could be best customized to satisfy the needs of the project. The *OneZoom* consultants informed the team that there were two different versions of *OneZoom*: the "complete" version that used an older codebase with no future updates, and the "kiosk" version, which was a version with limited functionality and was designed for museum touch screens. Although the "complete" version was no longer being maintained and updated, installing and running it would still allow the team to understand how datasets were transformed into the interactive and dynamic format. This was extremely important for the project because our goal was to import datasets that reflected evolutionary relationships among flagellate plants. The practical concerns, at this stage, were that the first author needed to be familiarized with the original software and its code. Therefore, the team decided to explore the "complete" version. This decision was important because the early exploration of this software

version served as a preliminary assessment of its function-alities. As a result of the exploration, understanding of the limitations of this version foreshadowed the team's later decision to switch to a new version, which will be discussed in the "Switch of *OneZoom* versions" section.

Development of the Voyager (February to May 2017)

With the design decisions in mind, the team got together to sketch the mockup of the *Voyager* homepage, the color scheme, the structure, and the navigation of the *Voyager* before implementing the design. In this stage, existing orientations (skills) of stakeholders came into play particu-larly vigorously (Boschman, McKenney & Voogt, 2014), and much negotiation was on, including abundant content without compromising the user experience. The team used the open-source WordPress content management system for the *Voyager*, because of prior experience of team members and the ease and user-friendliness involved in customizing existing WordPress themes. This decision is appropriate because WordPress' abundant choices of plugins allow for various forms of content presentation on the *Voyager*, for example, using the blogging feature and the Tag Cloud to sort activities. Following the shared design decisions, the *Voyager* would use a) a green color scheme to reflect the plant theme of the website, b) a responsive WordPress theme template that allows the website to dynamically fill and shrink based on the size of the website browser window. The dynamic theme is essential in ensuring a pleasant user experience across all kinds of mobile devices. The resultant information architecture for the *Voyager* homepage consists of 6 image-based buttons to a) point the users to the core *Voyager* sections containing educational information and activities, and b) to provide a usable, "tappable" interface for those students and instructors who use the website on touch devices.

Once the first author implemented the *Voyager* design, she met with the education SME (professor in educational tech-nology), and then discussed the design to the entire team, a common design practice in both instructional design and user interface design (Branch, 2010; Rogers, Sharp, & Preece, 2011). Using the feedback, the first author refined design to make the entire image buttons clickable, added the affor-dance to enlarge the image buttons upon the mouse-over action, simplified the structure of the navigation menu, and so on. While the team added more features in the subse-quent phases, the *Voyager* was ready by the end of May with the main structure and page holders for future instructional content to be added. The six sections on the homepage are explained next.

The first *Voyager* section, "Phylogenetic Tree", takes the users to the customized *OneZoom* application that shows the biological relationships among thousands of flagellate plants, that is, the focus of this project. The zoomable and clickable leaves and nodes on this visualization of the Tree of Life (Soltis et al., 2018) open up detailed information, which is conveniently retrieved dynamically from existing scien-tific databases, such as Encyclopedia of Life (EOL) and the National Center for Biotechnology Information (NCBI).

"Lessons and Activities" is another important section of the *Voyager* website. It houses a number of cyberlearning activ-ities developed by our interdisciplinary team of education and biology experts. These include citizen science projects, inquiry-based modules with storytelling features that can be plugged in either face-to-face or online classroom instruc-tion or informal exploration. Curricular activities are aligned with the Next Generation Science Standards (National Research Council, 2012; 2014) and designed for different age groups (elementary, middle and high school, and undergrad-uate classrooms) will also be available here.

The "Morphology" section serves to house botanical infor-mation about morphological traits and vocabulary. Clickable sound clips for pronunciation will be provided to familiarize young learners with complex plant names in Latin (scientific name), and common name in the native language (English and Spanish). "Case Studies" contains a list of controversial and intensively-debated topics in Botany, such as the evo-lution of the land plant lifecycle and phylogenetic optimiza-tion, and challenges learners to look for evidence that helps address these controversial issues. "Evolving on Land" is a section that allows learners to explore specific characteristics and adaptations associated with flagellate plant evolution. Finally, "Explore Your Backyard" is designed primarily for younger audiences and offers downloadable lists of flag-ellate plants that provide young learners or their teachers or parents with local plant information and encourages children to look for these plants in the natural environment. This allows learners to learn how to identify these plants in free exploration and encourages them to better relate to the nature around them.

After several cycles of iterative design of the *Voyager* homepage based on team feedback and the CDR process, the first author finalized *Voyager* version 1 and set it up on a local MAMP (Macintosh Apache, MySQL, PHP) server. After additional usability testing focused on page load times, the first author moved the *Voyager* online to an external web hosting service in November 2017 (see the *Deploying the Voyager and OneZoom online* section for more details on the web hosting CDR negotiations and considerations).

Early exploration of OneZoom (April to May 2017)

As the project team discussed and implemented important considerations for the *Voyager* design, the first author engaged in establishing a collaborative relationship with the London-based developers of the open-source *OneZoom* application. Early discussions with *OneZoom* developers focused on the affordances of each *OneZoom* code version.

The team learned that the London-based *OneZoom* development team was then working on a "latest" version of *OneZoom* with enhanced functionalities and usability. However, the development was still ongoing and would likely take another few months before it was ready for testing and the kind of customization that our project required.

This uncertainty created a level of additional anxiety among the project team. In this case, the priority of the team was to have the latest version of the customized *OneZoom* with the best functionalities (i.e., linking to scientific databases, supporting touch screen, and allowing custom data); the practical concern (Boschman, McKenney, & Voogt, 2014) was the uncertainty of how much time the latest version would take before being ready to be tested. The team reviewed the timeline of the design processes and proposed that the first author would continue to explore the already-available but somewhat outdated "complete" version of *OneZoom*. The team would decide later, depending on when the latest version was ready, whether to switch versions.

Understanding the computer code of the *OneZoom* software requires a lot of nuanced technical knowledge in multiple computer languages, such as JavaScript and Python. A number of videoconferences were set up between the first author and the *OneZoom* consultants to discuss how the *OneZoom* computer code was structured and what key changes were being made to the new and updated version of the software. After getting a general understanding of the file formats and layouts that the software relied upon, the first author tested it with a small dataset in the "complete" version of the software and visualized the data as a dynamic *OneZoom* tree.

Switch of OneZoom versions (June to July 2017)

After extensive exploration and testing of the code, the first author was able to get the "complete" version to work with the dataset, but also continued communicating with the *OneZoom* consultants in terms of updates on the latest version. The consultants informed the team that the development of the latest version was ready to be tested in mid-July. A set of follow-up in-depth videoconferences were performed with the first author to discuss the functionalities and limitations of each OneZoom version. The "kiosk" version, which did not support linking to large public databases such as The Encyclopedia of Life and Wikipedia, was not considered at all. Although the "complete" version links to the open, public databases, it does not support touch screen functionality (the affordances and restraints of each version are listed in Table 2). The latest version, while still undergoing through final stages of development, links to public databases and supports touch screen. The team decided that having the first author test the latest version will be beneficial to both the software consultants and the team. The reason was that the first author would be among the first collaborators to test the software's new code, and whenever there was a problem, the consultants would work closely with the first author to solve it. The first author briefed the team with the situation and shortly after, the team approved the decision to switch to the latest version of *OneZoom*. This decision adhered to the practical concern aspect of the conceptual framework as this was the most feasible among all choices. Although this decision led to a more complex software customization process, successful implementation and deployment (discussed in the next sections) of *OneZoom* resulted in a customized version that met all the major expectations of the team.

Development challenges and evolution of OneZoom (August to October 2017)

From the development perspective, testing the latest version of *OneZoom* on the local server (localhost) is the most challenging part of the entire design process. To customize *OneZoom* using the latest version of code, as instructed by the consultants, the first author first downloaded and installed *Python*, *Web2Py*, *MySQL server,* and *MySQL Workbench*. To run *OneZoom*'s JavaScript and Python scripts, the *Grunt*

THE KIOSK VERSION	THE "COMPLETE" VERSION	THE LATEST VERSION
• supports touch screen functionality; • does not support linking to Encyclopedia of Life (EOL) or Wikipedia; • codebase is not supported by developers anymore; adding functions could be difficult and less worthy than working with the latest version.	• links to EOL and Wikipedia; • does not support polytomies in the data; • does not support images in the tree; • does not support touch functionality.	• links to EOL and Wikipedia; • supports images in the tree; • supports touch screen; • supports polytomies; • the team's institution obtained a license to update OneZoom code for the latest version; • using custom data would be more difficult • dealing with the server environment would be more difficult.

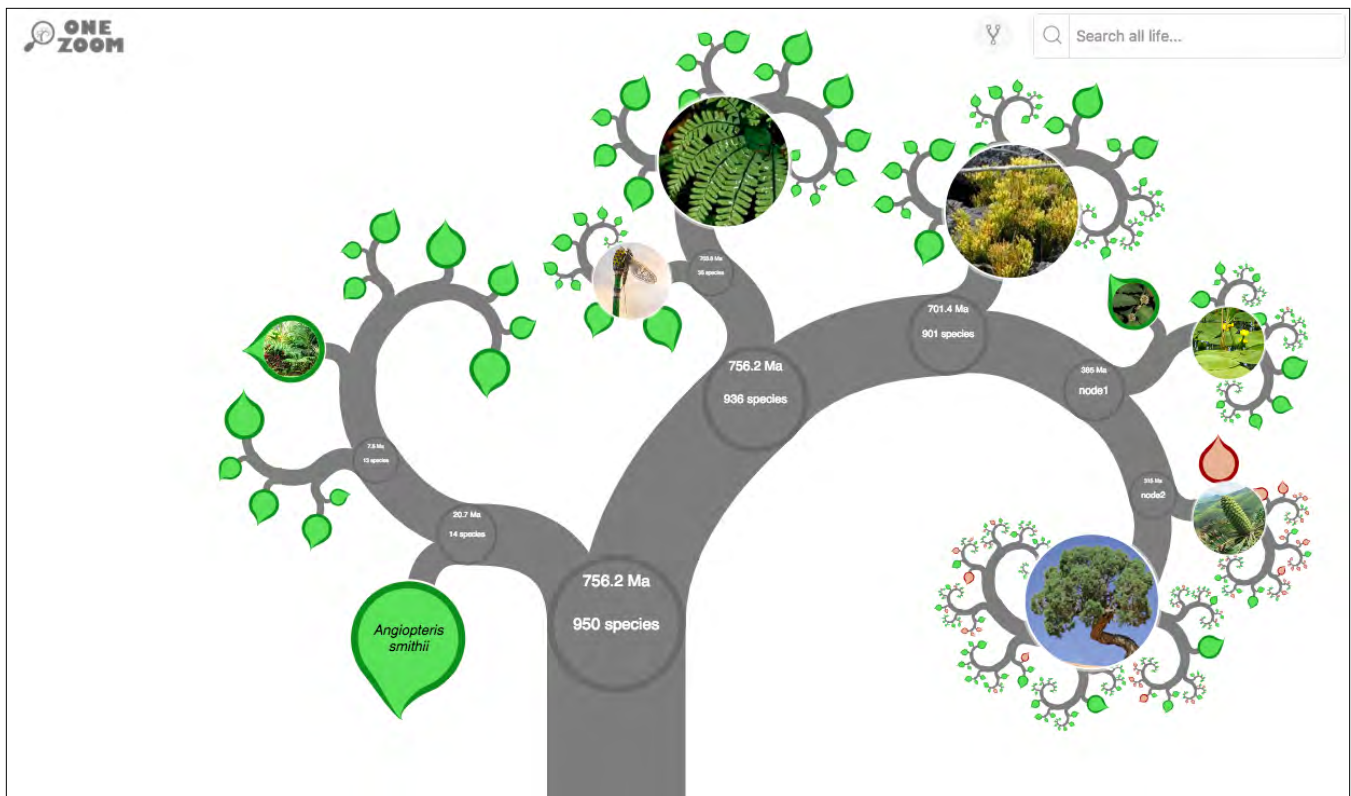**TABLE 2.** Comparison of the three versions of *OneZoom* code

FIGURE 4. Customized OneZoom with test data on flagellate plants (used with permission).

task runner, the *npm* package manager, and other libraries were also downloaded. Next, the first author retrieved the latest version of the *OneZoom* code from *GitHub*. Then, the Web2Py server was run in the *Command Line* to run *OneZoom* locally. The major challenge in this stage was that the first author had no prior experience with most of the tools mentioned earlier. Therefore, besides requesting a minimal amount of help from the software consultants, she frequently and diligently consulted online programming forums such as the *Stack Overflow*, trying to find instructions on how to accomplish these tasks using *command-line* in the Terminal application on Macintosh.

Next, the first author imported a database dump (i.e., an *SQL* file) with the test data to the local database in *MySQL Workbench*, where editing of the database tables and content using *MySQL* took place. During the process, the first author and the consultants used the collaboration tool, *Slack*, to problem-solve and debug the code. After successful testing on the local server, the team reviewed the adapted *OneZoom* interactive map and confirmed that the customized version (Figure 4) met the expectations.

Deploying the Voyager and OneZoom Online (November and December 2017)

External priorities, another important component of the CDR framework (Boschman, McKenney & Voogt, 2014), such as availability of funding and external deadlines, pressured the development work to be finished by early December. After considering the restraints in resources and time, the team selected the PythonAnywhere hosting, rather than the virtual private servers (VPS). Configuring the VPS for both the *Voyager* and the *Web2Py* application (*OneZoom*) on a Macintosh computer required more expertise that team members possessed, compared to hosting the *Voyager* and *OneZoom* separately. The only drawback regarding separate hosting was that it would put *OneZoom* under a different web domain than the *Voyager*. After weighing the advantages and disadvantages, the team considered using PythonAnywhere to be the most feasible option for the situation and purchased two different web domains and hosting services for the *Voyager* and *OneZoom*. As a result, *OneZoom* is now linked to the *Voyager* under the "Phylogenetic Tree" page but is actually hosted on a completely different server—one that is optimized for running web Python scripts—PythonAnywhere. The customized *OneZoom* is accessible by clicking the image button on the *Voyager* homepage and then the tree image on the following page.

This design case illustrates that CDR as a collaborative design reasoning process was influenced heavily by all three hypothesized CDR components: that is, external priorities, existing orientations, and practical concerns (Boschman, McKenney, & Voogt, 2014). The process is challenging, and collaboratively making decisions requires a lot of

coordination and willingness to learn and consider all stakeholders' perspectives (Kvan, 2000).

IMPLICATIONS FOR FUTURE WORK

While working with an interdisciplinary team to design and develop an interactive learning tool may not be unique, conflict resolution and negotiation during this design process is and can inform future design decisions. For example, one unique aspect of our design was selecting the best version of an open-source application while the application was still undergoing development. What our selection (the latest version) entailed was working outside the team's comfort zone—leveraging a broader range of technical knowledge (programming languages and tools), more complex manipulation of data on the remote database, and so on. However, it is well worth the effort as the final product meets all major design goals of the team.

Team members usually bring in unique orientations and expertise, which require careful orchestration to bring out the best result. In our case, on one hand, the content experts' (Botany instructors and professors) priority is to present abundance content; on the other hand, the educational technology professor's priority is to present content in a clean way that does not compromise user experience. Therefore, acknowledging content experts' need to include extensive content on the *Voyager* and finding the best way to present content based on instructional design principles is a constant "bargain." Negotiation and conflict resolution were only successful because the team collectively searched and tested different resolutions.

Most development and customization in this project was performed by an educational technologist with entry-level knowledge of web programming, *HTML*, *MySQL*, and *command line*. Although this work is achievable for someone who is not a computer science or software engineering expert, customization of open-source software is often a very complex process and usually involves an understanding of different programming languages, data management, and often a variety of computer software programs (Antonenko, Toy & Niederhauser, 2004; Lakhan & Jhunjhunwala, 2008). It is highly recommended that the development leader on the team knows at least one of the major programming languages, such as *JavaScript* and *Python*, and has some understanding of *MySQL* and *command-line* scripting. What is equally important is to be open-minded and be proactive in upgrading one's development skills as required by the external constraints and practical concerns related to the project (Boschman, McKenney, & Voogt, 2014).

Besides requiring knowledge in front-end and back-end development, software customization is a technical job that also requires an understanding of the software and efficient communication with the software consultants or original software developers in terms of technical requirements and customization needs. In this case, the first author had to learn about the *Web2Py* framework that the original software was developed with and how to run software scripts using specific tools such as the *Grunt* task runner and the *npm* package manager, etc. This project confirmed that the moderately coupled collaboration with the software consultants assured the success of the customization of the software (Case & Lu, 1999).

The development of this interactive learning tool would not have been possible without the resources available in online communities of practice (Wenger, 2011) such as programming forums *Stack Overflow*, the *PythonAnywhere* forum, and so on. One should be able to take advantage of the answers and solutions proposed by experts in these online communities. In this case, most problems were solvable after piecing together instructions and guidance from different online communities. However, it was also realized that instructions were often lacking and unclear for specific situations such as configuring VPS hosting for both a *WordPress* website and a *Web2Py* web application. Nonetheless, the first author posted questions in those online communities and received useful solutions that were instrumental in project completion.

TYPE OF SKILLS AND RESOURCE	TECHNICAL	COMMUNICATION	RESOURCES AND FORUMS
PLATFORM AND TOOLS USED	• HTML, • MySQL, • Command-line, • JavaScript, • Python, • Web2Py framework, • Grunt task runner, • Npm package manager, and so on.	• Asynchronous (emails, Slack conversations, etc.) • Synchronous (Skype, face-to-face meetings, etc.)	• Stack Overflow, • The PythonAnywhere forum

TABLE 3. Platforms and resources used in the customization of *OneZoom*.

The design of this interactive tool was successful because the team implemented the collaborative design guided by the CDR framework (Boschman, McKenney, & Voogt, 2014; Case & Lu, 1999; Kvan, 2000). With shared goals, clearly defined roles and responsibilities, and a variety of expertise, the team discussed difficulties encountered in a candid, constructive, and timely manner. The team effectively combined asynchronous (emails, *Slack* conversations, etc.) and synchronous (*Skype*, face-to-face meetings, etc.) communication for executive decision-making. Table 3 provides a listed view of the skills and resources involved in this design experience.

CONCLUSION

This paper describes the collaborative design reasoning processes that the project requires to effectively design and develop an online interactive learning tool following the loosely and moderately coupled collaboration model (Case & Lu, 1999; Kvan, 2000). The success of this project confirms that collaborative design reasoning is a useful conceptual framework in guiding the interactive learning tool design and development work where team members with different expertise and defined responsibilities are brought into the project to achieve a common goal. The three components of the previously published design reasoning model (Boschman, McKenney, & Voogt, 2014)—existing orientations, external priorities, and practical concerns—played an important role in all collaborative design decisions. It is hoped that this article will be of practical help and provide some insights into the complex processes of bringing an interactive learning tool live.

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