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Educational Outreach & Stakeholder Role Evolution in a Cyberinfrastructure Project

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***Abstract*—Over the last several years, a growing body of work has examined the nature of large-scale virtual organizations for data-intensive cooperative science. These projects, known as Cyberinfrastructures (CI) in the United States, are established realms of inquiry for the eScience and Computer Supported Cooperative Work (CSCW) communities. Scholarship in these communities extends technology focused inquiries to investigate the sociotechnical concerns to such infrastructure creation and maintenance. In this paper we present findings from our qualitative study of a federated cyberinfrastructure organization known as GENI. We contribute to this body of scholarship by investigating how stakeholders in the GENI project position existing, and newly created, resources for use in educational settings. We examine how stakeholders acquaint new potential stakeholders with this CI in order to draw them into the community, and the ways in which stakeholder's roles evolve over time. Our findings illustrate several ways stakeholders leverage and align existing relationships and resources to expand the CI project's user base. Finally, this paper suggests avenues of further inquiry and implications for organizing future CI projects.**

Keywords— Cyberinfrastructure; synergizing; educational outreach; Computer Supported Cooperative Work (CSCW); qualitative methods; scientific collaboration.

I. Introduction

Cyberinfrastructure (CI) projects are virtual organizations creating and using advanced computational and big data resources to help researchers examine increasingly complex scientific questions [1-4]. CIs are multifaceted, distributed, and multidisciplinary organizations. Scientific cyberinfrastructures are designed to support collaborative science among multiple research contexts. A great many scholars in the eScience and Computer Supported Cooperative Work (CSCW) communities have investigated how CIs are implemented [5-7], but in order to accomplish their goal of supporting science, a CI's virtual organization must endure over time [8, 9]. Simply building systems or sets of resources will not result in success. These resources must be adopted by stakeholders and continually replenished if they are to be useful. A cyberinfrastructure project must create a thriving sociotechnical environment that will last over time. eScience and CSCW studies of CI development illustrate the different temporal concerns of these projects [8, 10-12] even when the project may not yet be meeting its infrastructural goals [13].

Previous research shows that cyberinfrastructure projects are sustained and maintained by perpetually aligning and realigning relationships among people, practices, technologies, and organizations [9, 13, 14]. In our previous work on sustainability in the same cyberinfrastructure we are investigating in this paper [14], we posited that the development and maintenance of CI projects requires the constant addition of new stakeholders, especially as users drop away over time. We proposed that establishing a process whereby new users can be constantly recruited is necessary for the cyberinfrastructure project to succeed. In that same research we identify multiple enrollment and aligning practices in a CI project that supports its development and sustainment, including work conducting outreach activities. This paper extends that research by examining how resources for outreach activities are being created and positioned to try and help enroll new CI stakeholders through outreach in educational settings.

The Global Environment for Network Innovations (GENI) is a pioneering program of four interrelated CIs, which exist together in a federation governed by a central project office. In this paper, we describe the resources of this CI project that stakeholders' position or create for use in the educational settings of formal undergraduate and graduate classes at universities across the United States. We examine how these CI resources are positioned by expert users and administrators in the GENI project to be functional for stakeholders in educator roles—teaching and mentoring undergraduate and graduate students in lab or classroom settings—so that they can use the CI and its resources in their teaching. We find that these positioning practices [14] enable existing stakeholders in the GENI organization to use the project's resources in settings beyond the primary research context as well as to work to draw new potential stakeholders into this CI's community. This research investigates the following research question:

How do stakeholders in the GENI cyberinfrastructure project leverage relationships and position resources for use in educational settings in order to grow its user base?

In order to answer this research question, we will first conduct a brief review of the literature surrounding cyberinfrastructure projects and the synergizing framework we will be using as a lens for studying the GENI project. We will then lay out the methods we utilized in this research, before discussing our research findings and the conclusions we have drawn from this study.

II. Literature Review

Scholars across multiple disciplines including eScience, Computer Supported Cooperative Work (CSCW), and Information Science [8, 9, 13-15] have been investigating the development of cyberinfrastructures since the mid-2000s [3, 16, 17]. Cyberinfrastructures are comprised of high-performance computational and networking technologies, very large data sets ("big data"), and a multimorphous human infrastructure that most often engages multiple organizations and stakeholders [4]. Sociotechnical studies of CI draw upon Star and Ruhleder's [18] notion of relational infrastructure to examine these systems and the organizations creating them. Research on CIs has shown these organizations to be highly emergent, fluctuating and evolving over time [2, 19].

Designing, building, and using CI is not a simple endeavor. The relational aspects bring forth extremely complex technical and social challenges for the design of CIs, as well as their maintenance and sustainability over the long term [10-12, 20, 21]. CI studies examine the varying temporal scales of the design, development, and maintenance of these large-scale projects by focusing on the different organizational arrangements and concerns of these nascent endeavors. Karasti and Baker [20] emphasize that resources in a CI must be designed for not only near-term use but importantly for change in the medium to long term as research goals of the project change and stakeholders come and go. Ribes and Finholt [8] similarly discuss tensions inherent to the "long now" of developing infrastructure for scientific research, in particular that of building systems to meet current goals versus that of designing those which can be sustained over time.

Prior work in the eScience community has highlighted how CIs and educational settings are tightly knit, be that through CIs supporting education or educational usage sustaining CI projects. Smith et al. [22] looked specifically at how students could utilize an existing CI project to further their understanding of the environment. In that case the CI allowed students access to tools they would ordinarily never be able to access, exposing students to technologies which they might wish to revisit in the future. Likewise, Yalda and Clark [23] investigated how a complex cyberinfrastructure designed to study the weather could be successfully used by students through the utilization of interfaces which abstracted the complexity of the platform. This resulted in giving students access to the same data as scientists, allowing them to utilize this data to further their learning and expanding the CIs userbase despite the student's lower technical and scientific competency. Numerous other eScience scholars have also noted this relationship between educational settings and Cyberinfrastructures [24, 25], in this paper we add to this dialogue by investigating how CI project resources are positioned to be useful to stakeholders in educational settings, taking elements of the CI and using them in contexts that they were not originally designed for. This raises implications for future research and potential policy that we discuss at the end of this paper.

This paper specifically focuses on the multimorphous human infrastructure of CIs [4] that is often positioned to support distributed collaborative projects spread across multiple organizational, geographical, and political boundaries. The human infrastructure is a complex array of social and relational aspects. Cyberinfrastructure projects differ from many traditional types of systems in that their users and stakeholders are not always specified or known ahead of time [19, 26], nor do they have a fixed physical, cultural, or organizational boundary in which they operate [14]. They are embedded within and across multiple organizations, technologies, and communities of practice, often simultaneously [18].

Ackerman et al. [27] theorize resources as "an entity that is used in a particular manner to address a recurring need or problem. A resource's manner of use is characterized by shared expectations, understandings, and practices that have built up during the history of its use in a specific environment" (p.310). The focus on the organizational work and different temporal scales in cyberinfrastructure studies somewhat backgrounds examination of a CI project's resources. Ribes [28] theorizes how a cyberinfrastructure sustains resources for different scientific goals over time. Bietz et al. [13] theorize the notion of synergizing work in cyberinfrastructure, explaining how resources that cross organizational boundaries are wielded for a CI project. We employ this lens in this paper to help us characterize the work interviewees describe in our study.

Synergizing is the "work that developers of infrastructure do to build and maintain productive relationships among people, organizations, and technologies" [4]. The notion of synergizing recognizes that infrastructures are not just stand-alone structures, but rather are embedded into, within, and across pre-existing technologies, social arrangements and sociotechnical structures [13]. Synergizing is a systems-level, relational view of infrastructure. It is typified by a process of successfully combining a multitude of human, organizational and technological entities to create a greater combined effect. Through the utilization of synergizing as a theoretical concept it is possible to more fully consider the relational structures of cyberinfrastructures and better identify how those structures affect the cyberinfrastructure over time [9]. Synergizing contains two sub-processes, which denote specific types of work activities:

Aligning – this is the work done by developers (any stakeholder in a CI project in Bietz et al.'s usage) to create functional compatibility between an organization's many human and non-human elements, so as to form productive relationships between the entities [13].

Leveraging – this is the process by which existing relationships between (and across) organizational elements are built upon or strengthened in order to reinforce an already existing relationship or create a new productive relationship with another organizational element [13].

In our prior work on GENI [14] we drew upon synergizing and actor-network theory [29] to understand stakeholder positioning practices in CI development. They focus on the relationships necessary to create and maintain a functional CI. We similarly looked at GENI to explain how stakeholders use positioning practices to develop and sustain CIs. In particular, we note that studies of "large-scale IT systems," similar to cyberinfrastructure, point to the need for a project to engage in "user advocacy" to promote the system to other stakeholders and potential new users. Briefly explaining that the GENI CI project engages in user outreach to try and draw in new stakeholders by leveraging relationships and trying to solidify existing ties among stakeholders. We did not however examine any particular instances of outreach. This paper extends and complements our previous work studying the GENI project by focusing specifically on the educational relationships of GENI stakeholders to try to grow the user base of this CI project as they position this CI project's resources for use in classroom settings. This paper addresses gaps in our previous work by looking specifically at educational outreach and how resources of the GENI cyberinfrastructure are positioned or created for this activity.

III. Research Site & Methods

We conducted an interview study of the Global Environment for Network Innovations (GENI) cyberinfrastructure project. GENI is a unique CI founded in 2005. It is comprised of a collection of four constituent and interrelated CIs (known as ORBIT, ORCA, PlanetLab and ProtoGENI). Commonly referred to as a federated cyberinfrastructure, GENI is a US National Science Foundation (NSF) funded program created to be a "virtual laboratory for exploring future internets at scale" [30].

Each of the four constituent CI have their own limited management structure, while GENI itself has two levels of management. At the very top there is the NSF, who as the sponsoring agency are the primary source of GENI funds. Below the NSF is the GENI Project Office (GPO) which deals with the day-to-day operations and running of GENI. Most of the NSF funds for GENI are administered via the GPO. The GPO oversees grants, equipment procurement (i.e. server racks), organizes quarterly GENI Engineering Conferences (GECs), and sees to the smooth operation of the CI by making sure projects and experiments do not interfere with each other or otherwise negatively impact the operation of any of the constituent infrastructures.

We conducted a series of semi-structured interviews with 52 individuals involved in the GENI cyberinfrastructure over the course of two years starting from March 2013 to April 2015. Six follow-up interviews were conducted in early 2015 to gain further insight into how GENI is utilized in educational settings. This included an interview with the Manager who leads the GPO's efforts facilitating the CIs use in educational settings. These interviews assisted us in expanding our sampling around the issue of education outreach, building on data we gathered during our initial round of interviews. Each individual we interviewed was a stakeholder in GENI, including: Experimenters, Developers, GPO Managers & Principle Investigators (PIs), and Students (see Table 1). These individuals can take on different stakeholder roles in the project [31], discussed further below. The majority of our interviews were conducted in person at the quarterly GENI Engineering Conferences (GECs) or similar events, with follow-up interviews conducted over Skype. The names of all the participants in this paper are pseudonyms.

Interviewees were asked a wide variety of questions about GENI, including: details of their roles within GENI, how they became involved in the cyberinfrastructure, and questions about their experience of GENI in educational settings. In order to effectively triangulate our data [32, 33] we supplemented our interviews with additional participant observations of demonstrations, group activities, meetings and presentations that occurred at the quarterly GECs. We recruited a varied set of participants from across the four GENI cyberinfrastructures, as well as the administrative and funding agencies, to take part in our study. This allowed us to interview individuals with a diverse array of experience with GENI and its infrastructures.

TABLE I. Breakdown of stakeholder groups

Stakeholder Group	Number of Interviewees
Managers [PI / GPO]	8
Developer	12
Experimenter	17
Undergraduate and Graduate Students	15

The interviews were audio recorded and transcribed and lasted an average of one hour. A preliminary set of interviews were then open-coded using a grounded-theory approach [34] and jointly analyzed using the ATLAS.ti software package by two of the primary researchers. A coding scheme was then constructed which consisted of 48 codes across 13 different coding categories. All remaining interviews were then coded by the first author following the established scheme. The complexity of the GENI project led the research team to expand the codebook, which finally consisted of 87 codes across 34 categories. The interviews were then recoded by the same researcher. Codes in our final scheme covered themes ranging from collaboration (including interviewee's work with different individuals, organizations, and projects), the roles interviewees take on, how different resources are designed in the project, how GENI is being used in the classroom, how educators are enrolled, and how the user base is expanded, among others. The six follow-up interviews with educators were coded only once, using the expanded scheme. The research team then identified coding categories relevant to key topics around educational outreach, infrastructure development, and recruitment to the infrastructure. Memos were written on these topics then discussed by the authors leading to the findings here. Key to understanding the findings here is examining the different stakeholder roles our interviewees can hold as part of the GENI cyberinfrastructure.

A. Stakeholder Groups in the GENI Project

The GENI cyberinfrastructure was designed as a platform for researchers to conduct experiments which use new, alternative networking architectures that are different from the standard TCP/IP design of the Internet. GENI participants acted as members of four stakeholder groups: developer, experimenter, student, and GENI manager. GENI and the constituent infrastructures had computer scientists working as part of two distinct types of stakeholder groups: *Developers* who were involved in developing the underlying technologies, software, and architectures of the GENI platforms and *Experimenters* who were focused purely on running research

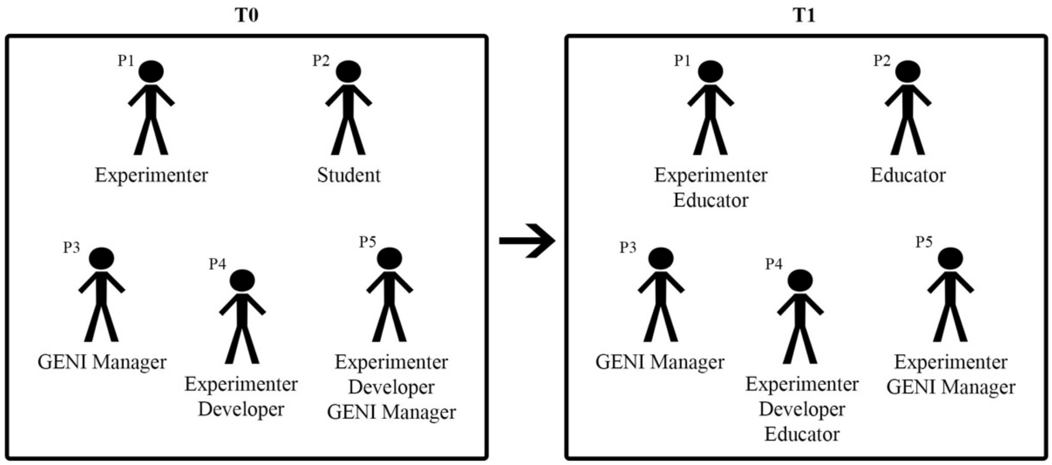

Fig. 1. Stakeholders can belong to one or more stakeholder group. Over time (in this case the transition from T0 to T1) individual stakeholders can join more stakeholder groups, or leave others.

experiments with the resources being created. GENI also includes many expert users and administrators who we collectively refer to as *GENI Managers*. GENI Managers are central, expert participants in the GENI community. These managers include the NSF project directors, high-level GENI Experimenters in each of the constituent infrastructures, and the managers at the GENI Project Office who are responsible for day-to-day operations. Finally, there are many undergraduate and graduate *Student* stakeholders contributing to this CI project.

As seen in Figure 1, which reflects participants' groups at the time of the interviews, individuals can belong to multiple stakeholder groups simultaneously and they can also change groups over time. For example, some Experimenters are also GENI Managers; and some students, in time, become Educators. In this paper, we are focused on one particular stakeholder group in GENI: *Educators*.

Educators use GENI as a teaching tool in their courses or labs. Most often Educators are faculty members who either use GENI as part of their research, and are long established Experimenter stakeholders (see P1 & P4 in Figure 1), or who have identified GENI as a useful platform for teaching after being exposed to it during their education (see P2 in Figure 1). In our follow-up interviews we spoke with 5 Educator stakeholders. Four of these individuals were GENI Experimenters and one a Developer; we also spoke with a GENI Manager supporting Educators. We identify each stakeholder group to which interviewees belong at the end of any quotes. Our findings examine how Educators position GENI resources to acquaint potential stakeholders with this cyberinfrastructure project.

IV. Findings

Stakeholders in the GENI project utilize a variety of resources for outreach activities in the undergraduate and graduate classes discussed by our interviewees (hereafter we refer to these classes as "educational settings"). In efforts to build and sustain the CI project's user base, participants create new resources and position already existing GENI resources through leveraging and aligning existing relationships and technologies.

Cyberinfrastructure projects receive significant amounts of funding from government agencies and private foundations to create resources for scientific research. GENI is a highly advanced and capable platform for running a variety of experiments in different fields. It is not just limited to computer science. However, any resource, no matter how innovative and powerful, will ultimately fail over time if it is not being used. Creating the infrastructure is only the first step. In order to build a research community people are required. The GENI Project Office maintains the philosophy that as a publicly funded resource the GENI project has an inherent responsibility to make sure the infrastructure is being used by as many people who can benefit from it as possible. This is why GENI resources are largely open for all to access and part of the motivation for the positioning practices we see in our data.

"A resource like GENI, if you don't take it to people and show them what it is, they're never going to end up using it. […] it's not so much, "What can they do for GENI" as much as "What can GENI do for them?" It is, after all, a nationally-funded resource, and hence more people across the country should be able to use it..." (Jessica, Experimenter / Educator)

In support of this philosophy, GENI Managers have endeavored to make the platform more accessible through the creation of a variety of educational resources and outreach activities. These resources and activities are utilized by a wide range of Educators in and out of the classroom.

In the following section, we identify specifically how GENI stakeholders are putting this philosophy into practice, through the adaptation of currently existing resources for use in educational settings, as well as the production of new bespoke educational resources designed to facilitate the use of GENI in the classroom. This organization of our findings is representative of stakeholders' opportunistic adaptation of existing resources for educational use, as they took advantage of new opportunities for educational outreach, and then creating new resources specifically to support this outreach work. The outreach activities we identify are a variety of different workshops and tutorials where the resources are employed.

A. Positioning Existing GENI Resources for Educational Outreach

GENI is comprised of a large variety of different tools and resources developed since the earliest days of the first constituent cyberinfrastructures. Many of these tools are bespoke and were produced for very specific tasks. However, over time several of these tools grew in popularity and were further developed into widely valued and used resources by stakeholders across the GENI project. We see that a number of these resources (GENI Portal, Desktop, and Wiki discussed below) were then positioned by GENI Managers specifically for use by GENI project stakeholders engaged in educational outreach at different universities or conferences.

GENI Managers expend effort to employ a wide range of resources in order to offer as much support to Educators as possible. Part of this support includes providing financial assistance where the GPO provides funds to Educators they have developed relationships with to cover the overhead of running workshops and tutorials, both at GENI Engineering Conferences (GECs) and at non-GENI conferences. The GENI managers also position existing resources by gathering and sharing materials as well as input from other Educators to provide curriculum support to stakeholders acting as Educators who are developing a new syllabus for teaching using GENI resources. Finally, the GENI Managers provide a great deal of general logistical and administrative assistance in supporting the use of existing GENI resources for utilization in Educational settings, maximizing the benefit of these resources to Educators. These resources include the GENI Portal & Desktop, the GENI Wiki, and GPO organized workshops and tutorials at the GECs. We'll now describe three of these resources then examine how they are employed in workshops and tutorials as educational outreach activities.

1) The GENI Portal & Desktop Resources: GENI Experimenters have a number of tools at their disposal for accessing GENI resources across the various constituent cyberinfrastructures. Two such tools which have proven highly popular with Experimenters are the GENI Portal and GENI Desktop. These tools provide users access to the different federated GENI infrastructures and were designed to provide a simpler approach to accessing GENI resources. The GENI Portal and Desktop are both single-sign-on web interfaces which are fully interoperable with each other. The Portal allows for the running of both simple experiments for beginners and more sophisticated experiments for advanced users, whereas the GENI Desktop provides much more abstraction lending itself more to novice to intermediate users in general. They are resources that stakeholders in the project as a whole uses to access the different CIs components. Both resources are leveraged by different stakeholder groups for use in educational settings, whether in workshops and tutorials for potential Educators or classroom activities with Students, as a way to provide simple and efficient access to advanced computer networking environments.

GENI Portal and GENI Desktop are used widely by almost every stakeholder group for simple, direct, and abstracted access to GENI. These resources enable individuals without deep technical knowledge to create an isolated container within GENI on which they can run experiments. These containers are known as GENI 'slices' and are built using resources from across all the infrastructures, as available and as needed. The GENI Portal & Desktop provide a layer of abstraction between the user and the components of infrastructure, while allowing users to make more complex adjustments and set up custom experiments as well.

Due to the flexibility and simplicity offered by the GENI Portal and Desktop, these resources are core elements in GENI classroom environments. Although their creation and development were totally separate from their current educational usage, Educators in the project identified these tools as being ideal for the classroom due to their ease-of-use and customizability. In the early days of GENI accessing the platform was very difficult for novice users. Logging in to GENI required a knowledge of command line interface and specific GENI commands. Eventually some Educators identified tools like the GENI Portal that might work in a classroom setting and successful tested using them in their classes. To build off of efforts Educators originated, GENI Managers have positioned the Portal and Desktop for educational outreach by leveraging these tools for use in new educational contexts. They did this by facilitating the creation of curricula around these resources and through the development of workshops and tutorials (see below) which introduce new potential Educators to the tools. They also help new potential Educators familiarize themselves with these resources. These potential Educators are more easily able to use the GENI Portal and Desktop in lessons because they are able to align these resources they are familiar with from their position as Experimenters in the overarching GENI project to the local teaching role that they have in the context of their university by relying upon the curriculum created at the encouragement of GENI Managers.

2) The GENI Wiki as an Educational Resource: The GENI project as a whole utilizes a centralized and openly available Wiki which contains information regarding all aspects of the federation and the constituent cyberinfrastructures such as: information about the GECs, details about the constituent infrastructures, workshop materials, projects related to GENI, information for newcomers etc. Much like the GENI Portal and Desktop, the Wiki was not created with an educational purpose in mind and already had a fairly high-level of utilization by GENI stakeholders prior to its positioning for use in educational outreach activities.

The GENI Wiki has been leveraged by GENI Managers to serve in educational settings due to its ease of use, availability, and the large amount of relevant information already hosted on it—the Wiki was already an actively used resource by GENI Experimenters in their work for example. Many of the resources for teaching classes (at workshops, in tutorials, or traditional classroom settings) are stored on the GENI Wiki. This resource is publicly accessible and open on the web and thus available to anyone who wishes to use its contents. GENI Wiki resources include materials produced by GENI Managers designed to guide instructors in how to run classes, as well as full curricula and sample experiments created independently by stakeholders already acting as Educators, so that others may have a resource to guide them in designing their classes.

"What we do is we put [the teaching materials] on the GENI WIKI and then anybody can use them. So sometimes we have requests from other schools asking, you know, for help to use these tools and these assignments and things like that." (Dora, Experimenter / Educator)

The GENI Managers encourage the placement of educational materials on the Wiki as a standard practice, and this has been successful in giving Educators access to a wide variety of educational materials. Given the repeated requests for materials and the low-effort required to place them on the Wiki, this standard has been of mutual benefit to both the Educators who have developed curriculum and to new Educators looking to utilize them. Additionally, there are advantages that new Educators can prepare classes based upon established materials that are already tried and tested, and experienced educators in computer networking also have easy access to new resources to further develop their syllabi and curricula.

For example, an Educator at University X may design a syllabus for an introductory networking class, and then develop it over a semester before placing it on the wiki. A new Educator from University Y then discovers the materials the following year when designing their own networking class and uses it as the basis for their syllabus. The Educator from University Y is able to leverage the materials created by an Educator at University X since the GENI Managers encouraged stakeholders to share educational resources through the common GENI Wiki. By promoting the use of the Wiki for storing and sharing educational materials the GENI Managers help to align new relationships between stakeholders from different universities teaching with GENI so that they can share and build upon each other's experiences since the Wiki is positioned accordingly.

3) Educational outreach activities at GECs: running workshops and tutorials – Workshops and tutorials are regularly held educational outreach activities scheduled at the quarterly GENI Engineering Conferences (GECs). Tutorials are the most common of these two undertakings, GECs tend to have several tutorials occurring throughout, and they cover specific topics like the 'How to use the GENI Desktop' or 'How to Run a Simple Experiment on GENI'. Workshops are events that occur concurrently with other GEC activities, they tend to briefly cover higher level topics like 'Using GENI in the Classroom', rather than going in-depth on one specific topic like a tutorial. These events are organized and run by particular GENI stakeholders who have been recruited by GENI Managers to discuss specific aspects of the GENI project relevant to their expertise. Most often workshops and tutorials enable novice members of the GENI community to develop their skills with a certain infrastructure, or tool, and provide hands on training with the infrastructure.

Workshops at GECs are usually overseen by the institution or project team responsible for the development of the artifact or infrastructure concerned at the behest of, and with the support of, the GENI Managers. Having identified these workshops as a useful means to engage in educational outreach, the GENI Managers began to organize occasional workshops themselves. These workshops are targeted towards Experimenters who wish to use GENI as a tool for education, primarily as a way to teach networking classes.

"We have done workshops specifically targeted to educators. It was a day long workshop where the instructors came, some who are using GENI some who are considering using GENI in the classroom." (Vance, GENI Manager)

The GENI Managers recruit experienced Educators who are currently using GENI in their teaching to run these workshops. They do this by leveraging the relationships they have developed with these Educators—who are most usually also experienced Experimenters or Developers—over time to encourage them to run the workshops. These leveraging activities also produce new relationships between the stakeholders attending these workshops (Experimenters who are potential Educators) and both the GENI Managers and the Educators who are running the workshops. These potential Educators are already part of the GENI community in some way, but through these activities they are creating new educational relationships with existing Educators and GENI Managers, as they gain first-hand knowledge about how to run and manage classes with GENI resources. This is not a spontaneous or independent transformation, as often these Experimenters already have teaching obligations, but the educational outreach activities help to guide them in the direction of using GENI for their classes. This enables these potential Educators to align their research work as part of the national GENI project to their local teaching obligations.

For example, a GENI Manager connects with an Educator from the PlanetLab CI (one of the four GENI CIs) who has run classes with GENI over several years and asks them to help run a workshop to introduce new stakeholders to using GENI in the classroom. That workshop is then attended by an Experimenter from the ProtoGENI CI, who is also a faculty member at University X. The Experimenter then returns to their University and begins to design a syllabus for one of their classes using GENI, becoming a new Educator and incorporating their specific ProtoGENI platform knowledge into their own educational materials. These new materials will then be shared back to the wider GENI Educator community via the Wiki or MOOC (see below), improving the Educator knowledge base.

B. *Creating New GENI Resources for Educational Outreach*

In addition to the three existing GENI resources described above, our interviewees discussed two types of resources created specifically for use in educational outreach activities (as opposed to pre-existing resources created primarily to support research work and adopted in outreach activities). These are the GENI MOOC and GENI Workshop Materials. These resources draw upon other resources from the GENI project and employ them specifically for educational outreach. The GENI project engages in educational outreach with these resources by holding training sessions specifically for new Educators to learn how to use GENI resources

1) The GENI MOOC Resource: The GENI MOOC (Massive Open Online Course) is a central repository for storing education materials. However, unlike the previously existing resources created for research work, the MOOC was designed specifically for the purposes of supporting GENI stakeholders in Educator roles. The MOOC is used to store teaching modules which include lesson plans, written materials, quizzes, and experiments that run a live GENI instance via a simple browser interface—making it a much more powerful tool for use in a teaching setting than the Wiki's static storage of materials alone. Educators can upload their own materials or use already existing resources. Additionally, GENI Experimenters who are not teaching can add materials to the MOOC so they can share their research by creating videos and setting up experiments which replicate their work. This ease and simplicity does come at a cost however. Experiments run using the GENI MOOC are very simple and so Students aren't able to make adjustments or do more complex tasks as they would in experiments using the GENI Portal.

"This GENI MOOC project, in which experiments are run in a browser and it's open to anyone, so you don't need to be part of a class or have an instructor [...] those are much simpler experiments and with less freedom for students to try different things." (Fanya, Graduate Student / Educator)

Through the creation of the MOOC, the GENI Managers have worked to align a wide variety of GENI resources and stakeholders into such a position whereby new functional educational relationships can be produced between these elements and the Educators who use the MOOC for running their classes. This follows a similar pattern to the GENI Wiki, where new Educators can build on existing materials to develop their own classes. However, with the MOOC Educators are able to go a step further and run experiments without needing to know the intricacies of the framework that supports it. For example, an Experimenter in the ORCA CI runs a simple experiment to test various infrastructure features, and then identify these experiments as useful tools for teaching basic networking concepts. Having become aware of the MOOC via a GENI Manager's outreach at the GECs, the ORCA CI Experimenter uploads their simple experiment to the MOOC, along with instructions where it is spotted by an Educator at University Q. The Educator at University Q, although unfamiliar with the specific intricacies of ORCA, is then able to implement the experiment in one of their classes easily since the materials in the MOOC are simple to use.

Although the MOOC and Wiki are very similar resources, each has vastly different usage patterns. The MOOC provides sample experiments to be used in the classroom, and houses the means to understand, plan, & deploy these experiments all in one place, and has no use beyond the classroom. Whereas the Wiki houses higher-level educational materials like lesson plans, syllabi, and instructions on how to access tools like the MOOC and Desktop/Portal, but doesn't provide any ability to deploy or run classes, it also has additional uses outside of an education setting (housing all kinds of information on GENI projects and personnel). Also, the MOOC is accessed by Educators to plan classes and Students to deploy experiments, whereas the Wiki is primarily a resource used by Educators.

2) GENI workshop materials as educational resources: In the creation and running of workshops, the GENI Managers and the Experimenters in charge create a large number of different materials to help guide Educators. As mentioned previously, GENI Workshops are held widely throughout the GENI Engineering Conferences, covering a wide variety of topics and tools, including specific education oriented sessions. These workshops are intended to expose individuals unfamiliar with the project's resources to the GENI cyberinfrastructures, and the GENI Managers run regular workshops targeted specifically at current and potential Educators to help guide them in the use of GENI resources in educational contexts.

Workshop materials comprise a number of unique resources in the form of detailed tutorials and instructions on different aspects of GENI, as well as PowerPoint slides of the materials covered and the invaluable human resources of first-hand access to the GENI Managers and individuals running the workshops. The materials serve as both guides during the workshops themselves and as references later. The materials allow Educators to understand what it's like to run a real-life classroom session with GENI, for example discussing how to troubleshoot issues that can arise when setting up and running multiple slices from the same location simultaneously.

The richness of the GENI workshop materials allows for the running of much more complex guided experiments than can be accomplished through the MOOC. GENI Managers achieve this by again leveraging the project's general purpose GENI Portal & Desktop for use in educational settings so that the tools are aligned to the specific needs of the Educators who can productively employ the resource in their teaching.

Ultimately these workshop materials are all developed to be shared and used beyond the immediate context of a GEC workshop. They are designed to be leveraged by Educators in their work in different teaching contexts. The workshops themselves are educational outreach activities while the resources created are aligned among GENI Managers, Educators, and the eventual classroom activities of these Educators at their own universities. The difference between the workshop materials and those of the MOOC are that the workshop materials are designed both to facilitate conducting the workshops and as a reference to aid Educators in designing and conducting their own classes after they have received hands-on instruction in a workshop. This is unlike the MOOC, where Educators do not receive any personal interaction from other stakeholders, and only have written materials to guide how they handle the educational materials contained within it.

3) Educational outreach: training sessions specifically for new GENI Educators: Beyond the educational resources discussed above, part of the GENI Manager's support for Educators comes from funding training sessions. These are known as "Train the TA" sessions and are held every few months. Despite their name, these sessions are designed for anyone who wishes to use GENI as a teaching tool (e.g. be a GENI Educator), not just those who will be acting as teaching assistants. The sessions are run by GENI Managers who work to align GENI concepts, tools, and resources in such a way as to create new relationships between potential new Educators and the tools they will need to understand, and stakeholders they will need to interact with, in order to teach classes using GENI. These sessions are conducted online over the course of two weeks and are one of the outreach activities that individuals from both non-GENI and GENI workshops utilize to familiarize themselves with GENI as an educational tool.

"Through [the Train the TA sessions] we introduce people to GENI and the focus specifically is on using GENI in the classroom. So we talk about resources available to the instructors and TAs". (Vance, GENI Manager)

Through the support of the GENI Managers, potential Educators, along with already established GENI Educators, are able to familiarize themselves with all of the tools and resources they need in order to run classes effectively. As a result, GENI is now being used at many institutions across the United States as a means through which to teach core concepts such as networking and cloud computing.

These training sessions function similarly to the education specific workshop sessions at the GECs, in that specific knowledgeable Educators are recruited by GENI Managers to share expertise with potential Educators from other institutions or CIs. These sessions often complement the tutorials at the GECs and are specifically targeted towards the topic of how to conduct a class using GENI. However, these sessions are different to the GEC workshops, rather than short high-level discussions, these workshops are much more detailed, in-depth and open. By focusing on potential Educators, GENI Managers expand awareness among potential stakeholders of the GENI cyberinfrastructures—especially among smaller institutions that do not have the resources to run a part of GENI:

"I ran this workshop last July – the focus was on curriculum. To many [Educators] GENI is still overwhelming […] they first have to also wrap their head around what this GENI thing is. Especially for instructors at small schools, which is where I think the benefit could be great […] because they don't have computing resources locally. So GENI is a fantastic opportunity." (Julia, Developer / Educator)

In engaging in outreach activities to enroll new Educators, and through their work to support existing Educators, the GENI Managers express a desire to promote and expand GENI. Over time, the positioning work by the GENI Managers seems to have been successful with the number of classes being taught using GENI increasing dramatically, from around 80 students enrolled in classes which utilized GENI in 2012, to upwards of 800 by the fall of 2015. This demonstrates an increase in not only class-size but number of GENI stakeholders in Educator roles as well.

"So sometime around the fall of 2012 and we started having significant numbers of students using GENI. There was much better tooling. It was a lot easier for students to access GENI, [through] the GENI Portal which is how most people use GENI now" (Vance, GENI Manager)

GENI is now being used at many institutions across the United States, as a means through which to teach core concepts such as networking and cloud computing. This has resulted in new individuals being introduced to GENI, some of whom may become future GENI stakeholders.

4) Cultivating New Stakeholders Through Educational Outreach: Among the individuals exposed to GENI through a classroom environment not all will continue using its resources once the class is completed. In fact, the majority may never cross paths with this infrastructure again. However, in our data we see that some Students do opt to continue using GENI in other projects—in some cases in thesis work and others in future professional positions at an institution connected to the GENI project. Additionally, we see that there are also some individuals who progress to a career in academia who choose to use GENI resources in their own classes. Several of our interviewees were individuals who had taken such a path, from first engaging with GENI through an educational relationship with an existing Educator before going on to use it in their own research work, and in some cases then using GENI in their own teaching.

"I would definitely say that [taking a GENI based class was] a major contributor to my decision [to pursue a Ph.D. using GENI] because, I was not a part of these conferences never thought about working on these kind of experiments. So it was great to have the hands-on exposure to this the state-of-the-art technology." (Dora, Graduate Student / Experimenter)

Our data illustrates a few instances of this cycle as well as others that were headed in this direction. While we cannot claim that this is a solid practice leading to the sustainability of this CI project we do see the need for additional research to examine such a point, as we discuss further below.

V. Discussion

Our findings illustrate how stakeholders in the GENI cyberinfrastructure are actively working to position its resources for use in educational settings These efforts demonstrate the constituent processes of the Synergizing [13] framework—namely Leveraging and Aligning—as GENI Managers & Educators work to build and maintain productive relationships among the stakeholders and organizations that comprise GENI. GENI Managers work to position existing bespoke tools (GENI Portal, Desktop, & Wiki) so that other stakeholders in Educator roles can leverage them in their courses. The GENI Managers also work with other stakeholders to create new resources, designed specifically for educational outreach (GENI MOOC, Workshop Materials, and training sessions for Educators) in order to facilitate the adoption of the GENI CI in educational settings. Leveraging their different relationships, GENI Managers and Experimenters help to create a sociotechnical environment that enables stakeholders in the overall CI project to take on Educator roles and function across the different constituent cyberinfrastructures, regardless of their home institution or of the constituent CIs with which they are currently familiar.

Many Experimenters in the GENI CI are also Educators who employ elements of the cyberinfrastructure as teaching tools and as a result expose their Students to the GENI community and its resources. The leveraging of different GENI resources for educational outreach provides Students with invaluable hands-on experience which better enables them to understand complex concepts. The positioning of GENI resources for use in the classroom is especially useful for smaller educational institutions. Such institutions often do not have access to the kinds of large-scale distributed networking technologies GENI is building. Through these ongoing alignment and leveraging activities, GENI stakeholders use their existing relationships and cross-cutting resources to foster a flourishing sociotechnical environment in which the project is able to more readily recruit new potential Educators. This ongoing work takes place and functions across multiple organizations over time as different resources are created and used by the GENI project.

The goal for these aligning and leveraging activities is that new Educators expose their Students to GENI, as they use the newly available resources to run classes, workshops and other events. Introducing new Students to GENI establishes their potential as project stakeholders, an influx of whom can enable the infrastructure's user base to continually be refreshed and sustained over time. This is achieved as the collective knowledge of the federation is absorbed and reproduced when new stakeholders are exposed to GENI as Students, and then continue on to become Experimenters and future Educators [26, 35]. This is seen as critical to sustaining the CI in our study, and echoes our prior research which established that when cyberinfrastructure projects don't engage new users and realign relationships they fail [14]. In fact, in our prior work on GENI [14] we noted the specific failure of one of GENI's constituent infrastructures–PlanetLab–which fell into a dormant state after continual failures to integrate it with the other constituent infrastructures. PlanetLab is also the only one of the four GENI infrastructures which did not have at least some of its Experimenters actively engaging in the outreach activities GENI Managers offered, the lack of integration and use in education settings may have contributed to its falling into a dormant state.

Facilitating educational outreach within a federated CI project, such as GENI, is a complex and multi-faceted endeavor. However, these activities are important for the long-term sustainability of the infrastructure, as they allow for not only the enrollment of new Experimenters, but also new Educators through both direct recruitment and the development of individuals who become exposed to the infrastructure through the outreach activities. With the continuous infusion of new individuals from the educational outreach activities, new ideas and ways of thinking flow into the infrastructure.

Earlier research has shown that conducting user engagement and education activities, including events such as workshops and academic courses, are crucial practices for engaging and building a user base [36]. Through the ongoing creation, use, and elaboration of social and technical resources for educational settings, GENI stakeholders create a stable but adaptable environment that is conducive for drawing in new users.

A. Implications for organizing future CI projects

GENI's implementations of educational outreach activities provide valuable insights for the future development of cyberinfrastructure projects. Policy and management decisions by managers, policymakers, and other cyberinfrastructure stakeholders are often made without the benefit of actual research. Our results provide a more comprehensive view of a range of different outreach activities and also how these activities are taken up by different groups of stakeholders. In this paper we lay out a landscape of stakeholders and outreach activities as a foundation for further research investigating outreach activities as both necessary social structures for the continued maintenance and use of cyberinfrastructure technologies and projects that support science, and also as types of cooperative work in their own right. In terms of practice, this work helps those undertaking new cyberinfrastructure building efforts to understand some of what has already been done and to begin new outreach efforts with more knowledge.

The first practical implication of this work is to understand some of the nuances within and between the different kinds of stakeholder roles. Different stakeholder groups vis-à-vis cyberinfrastructure technologies include what we call Students, Experimenters, Developers, Educators, and Managers (including funding bodies). Targeting "Educators" however requires some unpacking. Educators can include undergraduate students, graduate students, and faculty. Research faculty may or may not be taking on an educational role with student research assistants as an outgrowth of their research role. In the case of undergraduate and graduate students sometimes the educating is happening on a peer-to-peer level rather than in a more formal mentor-student or teacher student relationship.

For Educators and Managers alike, steps may be taken to understand and support the trajectories by which Students become Educators and how Students benefit from a ready-to-hand corpus of materials to draw upon as their roles evolve. Management and policy may also want to consider useful ways to support the formalization of practices and educational materials that support Student-to-Educator transitions and furthermore that this support is provided at levels suitable to experts and non-experts alike. Points of entry into becoming an Educator may also be found from those who are not primary users but who may be attracted to unique educational opportunities afforded by particular cyberinfrastructure tools and educational materials—as with GENI providing unique experimentation opportunities for computer networking students.

Stakeholders who manage cyberinfrastructure projects in whole or in part—e.g., CI Managers—have additional opportunities to help attract new stakeholders and retain existing ones. Our data show particular activities that Managers can undertake to cultivate the outreach activities of Educators described earlier. Managers can help drive educational outreach efforts with hand-on, personal involvement: supporting stakeholders by attending workshops in-person, having fixed points of contact for stakeholders interested in educational use, and supporting and formalizing grassroots development of materials for educational use. CI Managers can also work actively with university faculty to incorporate the use of their infrastructure as a tool for teaching basic concepts in infrastructure, cloud computing, and other related areas.

There are also opportunities to employ the many Experimenters and Developers who are highly familiar with the platform and also have faculty teaching positions in educational outreach activities. Stakeholders who run experiments on the cyberinfrastructure, or work to develop the infrastructure, are typically disconnected from activities involved in attracting or retaining stakeholders. However, they tend to become involved in growing the user base when they become Educators themselves, if they are exposed to the outreach activities conducted by CI Managers. CI Managers can take the opportunity to try to grow the number of classes which utilize the infrastructure and expose even more students to the platform by bringing these Experimenter and Developer stakeholders in as Educators.

This study also has practical implications for representatives of funding bodies and managers who have budgetary and managerial influence. These individuals can use their positions to encourage stakeholders to support each other's teaching efforts and to furthermore share educational resources and teaching and learning experiences. CI project managers may also look to actively recruit current and new stakeholders to help run workshops and provide educational materials for learning experiences of varying scope and duration and to share their course materials. Furthermore, recognitions of the existence of different stakeholder subgroups of Students and Educators with different needs for both research and education might require more resources. Outreach activities associated with a single CI project could be called upon to serve different stakeholder groups with very different research and educational backgrounds and aims. Managers of CI projects may want to consider up front how components of CI systems might be integrated into education efforts that will both help educate new generations of scientists but also to help cultivate a user base that can help grow and sustain the ongoing cyberinfrastructures that are helpful and often necessary for the conduct of certain kinds of science. While the setting of policies can be useful, this study finds stakeholders noting that funding the provision of both logistical and instrumental support was key for the continued undertaking of what we describe in this paper as outreach activities.

B. Limitations and future research on CI sustainability

Our study sampled a variety of stakeholders in the GENI project over a brief, two-year period. As such we cannot yet make claims on the project's long-term success sustaining itself by engaging in educational outreach. Future research would benefit from engaging with Student stakeholders: capturing the experiences of undergraduate through postdoc levels and their career trajectories over time. Studying informal learning would also provide valuable insights about the positioning and use of cyberinfrastructure resources by potentially illuminating more contexts in which this takes place as well as other resources we did not see in our data.

VI. Conclusion

A fundamental tenet of relational infrastructures is that they do not arise de novo [18]. Infrastructures are embedded in pre-existing structures, adapting and extending existing technologies, organizational arrangements, and practices. No one is entirely in charge of infrastructures in practice [37]. Sustaining a CI project is not about keeping one set of resources working perpetually; it is about fostering a sociotechnical environment in which the relationships among resources, stakeholders, and organizations can continue to change and grow to address changing needs. With this paper we have shown in part how the GENI CI project is fostering an environment that draws in new users through educational outreach where resources are positioned or created so that Educators can leverage the installed base of the project. As infrastructure researchers, developers, and managers endeavor to understand and support the complex, intertwined relationships that sustain scientific infrastructure projects—across organizational boundaries, funding streams, and changing research dynamics—educational outreach is a promising area of inquiry deserving of additional attention.

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