The Hour of Cyberinfrastructure (Hour of CI): Early Findings from Pilot Study to Build Cyber Literacy for GIScience

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***Abstract*—This paper provides an overview of the Hour of Cyberinfrastructure (Hour of CI), a project creating a suite of self-paced, hour-long lessons aimed at helping learners in the areas of spatial, social, and environmental sciences take their first steps in the path toward cyberinfrastructure. Using collaboratively developed lessons written in Jupyter Notebooks, the Hour of CI aims to lower barriers to cyberinfrastructure for next-generation scientists and scholars from broad and diverse backgrounds. Early findings based on a pilot of four lessons suggest our approach has created engaging and appropriately challenging lessons for diverse learners. The project will continue developing lessons to help learners build cyber literacy for GIScience and prepare them to tackle global problems.**

Keywords—GIScience education, cyber literacy, GIS

I. Introduction

Advanced cyberinfrastructure (CI) empowers the growing knowledge economy in the United States, and plays a role in defense, homeland security, agriculture and commerce [1]. Yet, numerous scientific disciplines have yet to fully experience the benefits of CI. These emerging compute- and data-intensive disciplines have been called the long tail of science [2]. This paper provides a brief overview of the Hour of Cyberinfrastructure (Hour of CI) project and highlights early findings from a pilot study assessing our success at lowering the barriers to entry to CI for a broad and diverse learning community focused on geospatial problems.

Geographic Information Science and Technologies (GIS&T) is a broad and multi-disciplinary group of fields that leverage conceptualizations, tools, and technologies for working with and exploiting geospatial data to help address complex challenges in our world from food, energy, water, to mass migration. GIS&T intersects many domains in the long tail of science including social sciences, health sciences, environmental sciences, and geosciences. To provide guidance in training and educating this broad and diverse group of learners, previous research established Cyber Literacy for GIScience as a framework for "establishing the essential abilities and foundational knowledge necessary to navigate and thrive in this new technologically rich world" [3].

The NSF-supported Hour of CI project aims to address a critical training gap by creating (1) an engaging and interactive training environment that helps beginning learners achieve cyber literacy and (2) supplementary curriculum materials to help instructors unfamiliar with CI bring it into their in-classroom and out-of-classroom activities. The one-hour duration of each lesson is easy to incorporate into class sessions, serving as a clear and accessible goal for students and instructors—try CI for one hour. Here we present early pilot study findings based on a "soft" pilot of four lessons introduced in a variety of learning settings with a major learner population consisting of graduate students and four-year undergraduate students spanning over 40 fields of study that align with geospatial science. These project findings are a first step aimed at addressing a key question for educators in the long tail of science: How do we introduce cyberinfrastructure to our students?

II. Related Work

A. The Hour of Code

The Hour of Code provides a one-hour introduction to various computer science topics that has reached over one hundred million students in over 180 countries spanning more than 45 languages. It provides free one-hour tutorials in coding for K-12 students [4], [5], and has contributed positive impact on diversity in computer science by helping increase numbers of female, African American, and Hispanic students participating [6], [7]. In many ways, the experience is more than just 60-minutes of programming and problem solving – it exposes learners to the idea that they can be a builder of technology rather than simply a consumer of it.

The Hour of Code is clear and concrete. Instructors know how much classroom time to dedicate to this activity—one hour. Importantly, the Hour of Code provides ample instructor materials. These factors make the inclusion of the Hour of Code easier for instructors, because many K-12 instructors have no

coding experience, which represents a barrier for instructors to teach coding in their classroom and ultimately limits learning opportunities for students. The goal is also clear for students—code for one hour. The goal is not to solve the most problems or write the most elegant code. Students with more natural inclination for coding achieve the same "one hour of coding" goal as those who struggle with coding. This clear goal contributes to accessibility for students (and instructors).

B. Cyberinfrastructure-related Training and Education

The Hour of CI project aims to complement existing CI-related training and education efforts, whether virtual or in-person. High-quality training materials to learn CI include HPCUniversity [8], NSF-supported Extreme Science and Engineering Discovery Environment (XSEDE) training materials and events [9], [10], and Cornell Virtual Workshops [11]. It is worth noting that many of these materials use examples from physics, engineering and computer science, which can present barriers to non-physics/non-engineering learners that may not have the requisite mathematical or engineering background. Other approaches have targeted broad audiences through the use of analogies and real-world examples [12]–[14]. A series of workshops including EduHPC and EduPar have provided a wealth of works and ideas for education and training in this area including a curriculum initiative on Parallel and Distributed Computing [15], [16].

C. GIScience-related Training and Education

The Hour of CI project also aims to complement existing GIScience training and education efforts, whether virtual or in-person. The University Consortium for Geographic Information Science (UCGIS) is the leading academic organization for GIS&T, and has produced a Body of Knowledge (BoK) that encapsulates many topics in GIScience [17]. UCGIS has co-hosted a bi-annual Summer School to train a select group of next-generation GIScientists in many of these topics. A NSF-supported CyberGIS Curriculum Workshop for Synthesizing Education Materials was held on April 2-3, 2016 in coordination with a series of NSF-supported CyberGIS Fellows that created curriculum materials in this area [18]. Hour of CI lessons complement recent advances in active learning pedagogies and instructional practices in GIS&T [19]–[23], as well.

D. Cyber Literacy for GIScience

Arising out of the CyberGIS Curriculum Workshop mentioned above, the concept of Cyber Literacy for GIScience emerged. It is defined as "the ability to understand and use established and emerging technologies to transform all forms and magnitudes of geospatial data into information for interdisciplinary problem solving" [3]. Eight core literacies spanning GIScience and computational science were identified: cyberinfrastructure; parallel computing; big data; computational thinking; interdisciplinary communication; spatial thinking; geospatial data; and spatial modeling and analytics.

III. THE HOUR OF CI

Hour of CI lessons facilitate self-driven exploration and problem-based learning using Jupyter Notebooks. Jupyter Notebooks are web applications that support live code, interactivity, and dynamic visualizations. The Jupyter platform is designed to bring notebook-centric computing to a broad audience by combining modern web browser technology with an open-source, extensible, and language-agnostic programming and display framework [24], [25]. Hour of CI lessons are hosted on the GISandbox, a science gateway for GIScience, running on XSEDE [26], [27]. Learners simultaneously learn CI concepts as well as gain hands-on experience using a tool employed by thousands of computational and data scientists around the world (Jupyter Notebooks), and the world's most advanced CI (XSEDE).

Hour of CI Lessons are implemented as a series of Jupyter Notebooks. Each notebook uses the RISE extension based on Reveal.js [28], which transforms each of them into an interactive slideshow-based presentation. Slides can include live code cells allowing learners to develop Python code as well as interactive web-based widgets written in the Data-Driven Documents, D3.js, library. Slides can also include Jupyter Widgets that provide web form-based interactive components such as buttons, radio buttons, slider bars, etc. RISE slides allow lesson developers to frame the content, arrange graphics, and create engaging materials as learners progress through the lesson. The lessons are freely available at http://hourofci.org.

The Hour of CI is inspired by the Hour of Code. The project team is creating a series of one-hour interactive lessons and a learning infrastructure that are easy for instructors to adopt even with little to no experience in the content or the use of CI. The lessons are designed for learners with no previous experience or knowledge in the topic, thus lowering barriers to access CI for both learners and instructors. It complements related efforts and materials by providing a first step, and then directing interested learners (and instructors) to these other materials, resources, and activities.

A. Lesson Structure

The project team is developing a suite of hour-long lessons that help learners build a core set of skills and knowledge to

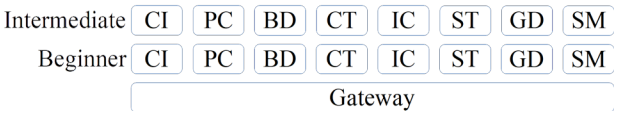

Fig. 1. Organization of the 17 Hour of CI lesson suite. One Gateway Lesson that provides a broad introduction, and a Beginner and Intermediate Lesson for each core area: Cyberinfrastructure (CI), Parallel Computing (PC), Big Data (BD), Computational Thinking (ST), Interdisciplinary Communication (IC), Spatial Thinking (ST), Geospatial Data (GD), and Spatial Modeling and Analytics (SM).

achieve Cyber Literacy for GIScience. To achieve this, lessons will span the eight core literacy areas that facilitate multiple learning pathways without any prerequisite knowledge or experience (Fig. *1*). This provides opportunities and challenges in terms of lesson development, because lessons can overlap in concepts and content and cross-references are often needed. However, this structure allows learners to control their own learning experience depending on their existing knowledge, learning needs, and/or career goals.

Each lesson is paired with a Lesson Plan, which helps guide even inexperienced instructors. The Lesson Plan provides a structured way of introducing the lesson and includes a

description of the learning objectives, a list of concepts that students will learn in the lesson, a guide on how to prepare the lesson, an instructional guide, and some basic tips for teaching the lesson. In addition, each Lesson Plan provides links to related competency and knowledge frameworks as well as cross-curricular activities and resources.

B. *Lesson Design and Development*

Hour of CI lessons are developed using a three-step Backward Design Process, which is centered on articulating student learning outcomes [29]. This curriculum design approach suggests that starting with identification of tangible learning objectives tied to assessment will lead to both better learning outcomes for students as well as better course design workflows for the instructors [30].

Student learning outcomes are commonly organized using Bloom's Taxonomy [31], [32] which identifies six levels of progression, each characterized by a set of student-centered characteristic expressions of knowledge, skills and abilities. Since the lessons in Hour of CI are short and introductory, they focus primarily on the Remember and Understand levels, which makes the simple interactive features provided by Jupyter Notebooks suitable as an instructional vehicle.

Our three-step design process begins by establishing learning objectives, which answer the question "What will learners be able to do after engaging with this lesson?" Once the learning objectives are established, lesson developers flesh out a framework for their lesson that establishes what concepts and skills need to be learned to achieve each learning objective as well as the order in which they will be introduced to build knowledge and skills. Importantly, the framework identifies assessments to test learner's newly acquired knowledge throughout the lesson. In the third and final step, the lesson is developed by translating the framework into a series of slides and executable notebooks. Throughout this process, learning objectives and the framework can be revised resulting in an iterative development process.

In addition to conceptual knowledge, Hour of CI lessons aim to give learners hands-on experiences that builds basic CI skills and engage their curiosity. Therefore, each lesson contains multiple opportunities for hands-on practice where learners are able to 'try-it' out and apply their knowledge to a theoretical or practical problem ranging from Python programming to spatial analysis. The capstone of each lesson is an 'Exploration' component that includes open-ended hands-on experiences. This provides learners who move through a lesson quickly ample time to explore so they remain engaged while learners who take a little more time can complete their journey through the Jupyter notebooks in the same hour.

To ensure variety within each lesson, we created a Lesson Framework Template to guide lesson developers through the development process. The lessons use several approaches to help keep learners engaged with the material, and avoid the trap of creating lessons that are structured as "concept, concept, concept, quiz", a style that is all too familiar in Human Resource-based training modules. The Framework Template has two key sections: Objectives and Concepts, and Lesson Segments. In the first section, developers outline their intended lesson objectives and list the related key concepts.

In the second section of the Framework Template, the lesson is divided into 4-8 segments (each ~5-12 minutes). Each segment aligns with a learning objective, introduces one or more *concepts* ("what"), explains "why" this *connects* to a student's life, sets the *context* for "when/where" this is important, and includes a hands-on *practice* component ("how") and an assessment. This structure helps lesson developers keep a lesson centered on learning objectives while infusing engaging hands-on experiences, relatable content and brief assessments throughout their lesson.

IV. Early Results

A. *Pilot Study Context*

While the project schedule originally intended to have a full complement of the Gateway and eight Beginner lessons ready for the Pilot Study, pandemic disruptions slowed development significantly. However, given the demand for online instructional materials, there was considerable interest in our project and we initiated a "soft" pilot study in the spring of 2021 that allowed instructors to test out the Gateway Lesson and multiple Beginner lessons.

To reach a diverse audience of learners that align with geospatial, environmental, and social sciences, we advertised the opportunity to pilot Hour of CI lessons in a number of disciplinary mailing lists (XSEDE Campus Champions, GeoTech Center institutions, University Consortium of GIScience, for example) to recruit pilot instructors. We provided pilot instructors with an instructor account and a list of learner accounts to "try" an Hour of CI with their students in their in-classroom and out-of-classroom activities.

Learners were encouraged to complete our voluntary end-of-lesson survey. We are reporting survey results from our "soft" pilot study to share our early experiences with and collect

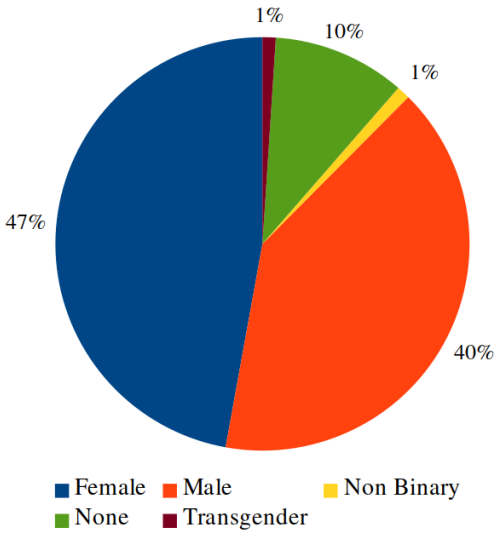

Fig. 2. Self-reported gender

feedback from the academic community to continue to improve lesson design, development, refinement, and data collection for the project. Our overall objective is to create hour-long lessons that are engaging and appropriately challenging for learners from diverse backgrounds many of whom are new to these CI and GIScience related topics, which aims to help us answer the broader question: How do we introduce cyberinfrastructure to our students? These early results can help gauge whether our lesson development process is creating engaging and challenging lessons that reach a broad and diverse audience of learners.

B. Learner Demographics

Here we report early demographic results from our end-of-lesson survey (n=193). We asked learners a series of questions in the survey including:

- What is your gender?
- What is your race or ethnicity?
- What is your field of study or area of expertise?
- What is your academic classification?

Participants were able to freely describe how they identify their gender, race or ethnicity, and field of study in open text boxes. Gender and race or ethnicity were manually coded into categories by one of the authors. Fig. 2 lists all reported genders in alphabetical order. Non-responses were coded as "None." Early results found almost half of learners identified as female representing the largest gender population in our early pilot program. Fig. 3 shows the distribution of race and ethnicity as reported by learners, listed in alphabetical order. Learners identified as primarily as White or Asian (totaling 65% of learners) with learners also identifying as Black (5%), Hispanic (9%), Multiple (races and/or ethnicities, 7%), and None (15%). These early results suggest that the pilot program has been relatively successful in bringing Hour of CI lessons to diverse learners.

We also aim to reach individuals from a broad and diverse group of institutions and areas of study. Early results show that

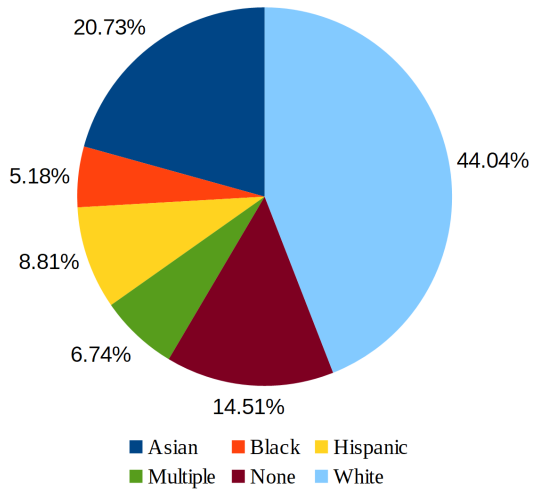

Fig. 4. Self-reported race and ethnicity of learners

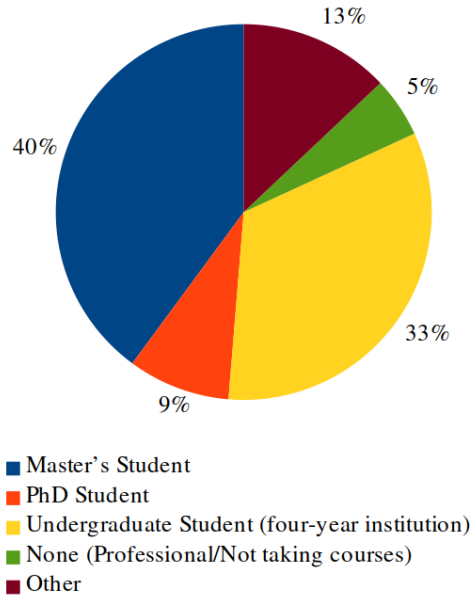

Fig. 3. Self-reported academic classification of learners

almost half of our learners reported being graduate students (PhD or Masters) and one third reported being undergraduate students at a four-year institution (Fig. 4). Learners from two-year institutions are not well represented in our early findings suggesting that more effort should be placed on reaching this demographic group. We identified over 40 fields of study ranging from architecture to urban and regional planning, computer science to global affairs, and geography to biology. These early results suggest that we are reaching learners from a broad range of academic fields of study, many that overlap with GIScience. We anticipate conducting further analysis of demographic information to see if we can identify underlying trends or themes across lessons once the pilot has been completed.

C. Gateway Lesson

We explore the Gateway Lesson as an exemplar to understand whether our lesson development approach has the capacity to create effective lessons. The Gateway Lesson is a broad introduction of the eight core knowledge areas. It is composed of seven segments centered on six learning objectives. The learning objectives for the piloted Gateway Lesson are:

1. Identify at least two examples of Cyberinfrastructure
2. Use Geospatial Information embedded in data
3. Use Jupyter Notebooks and Python to understand basic Python code
4. Visualize Geospatial Data using Geospatial Technologies
5. Identify the eight core concepts of Cyber Literacy for GIScience
6. Reflect on their own Cyber Literacy

Here, we report early results of our pilot program for the Gateway Lesson. We received 87 responses to our post-lesson

learner survey providing feedback for the Gateway Lesson out of 193 total responses for all lessons. The following early results are from a series of questions with responses on 5 point Likert scale ranging from “Not at all” (1) to “Very” (5). Early results show that 75% of learners rated the lessons content as engaging or very engaging (i.e., values of 4-5; Fig. 5). The content of the Gateway Lesson was relevant or very relevant to 74% of learner’s current role or area of study (Fig. 5). Over 80% of learners reported as the Gateway Lesson as being an effective or very effective way to spend an hour learning about CI (Fig. 5).

A key challenge for lesson development is aiming to create engaging yet challenging lessons for a broad and diverse audience. This is illustrated by the range of responses to questions asking learners if they were challenged by the content of the lesson: 34% were not challenged enough, 32% were too challenged, and 34% were appropriately challenged (Fig. 5).

Early results from our pilot program suggest that the Hour of CI lesson design framework produced a Gateway Lesson that was engaging to the vast majority of learners and they found that it was an effective use of an hour of their time. The level of challenge seemed to be fairly balanced across learners, although more work is needed to better understand why the lesson was too challenging for some learners and not challenging enough for other learners. There could be multiple reasons including differences in background and experience, level of education, or technical competencies/comfort. Learners reported that the lesson was relevant to their area of study, but that could be selection bias from recruiting instructors in fields that are adjacent or direct users of CI and/or GIScience.

Learners were also asked to provide feedback to help improve the lessons. We received a wealth of responses ranging from compliments on a smooth and engaging lesson to helpful critiques as well as a host of technical challenges encountered. Preliminary analysis did not yield any significant trend or thread to report here, but the pilot program is still ongoing. This feedback will be used to refine the Gateway Lesson, the Lesson Design Framework, and the Hour of CI environment to reduce difficulties and enhance the experience for all learners, which is all part of the iterative design and refinement process.

V. Conclusion

In this paper, we have presented an overview of the Hour of CI as well as early results from a pilot study being conducted as part of an NSF-supported project. Hour of CI lessons are designed based on a backward-design process using a novel framework template that provides a consistent structure for lesson development that balance building conceptual knowledge with practical hands-on skills. Lessons are designed to be engaging and appropriately challenging for learners from diverse backgrounds many of whom are new to these CI and GIScience related topics. The lessons, lesson plans, and lesson development guides are all freely available at hourofci.org.

In our early results, the lesson design framework was shown to produce an effective lesson based on learner responses to our end-of-lesson survey for the Gateway Lesson. Specifically, the majority of learners reported the Gateway Lesson to be engaging or highly engaging, challenged at about the right level, and the content was relevant to their current role or area of study. Many also reported that they found this was an effective way to spend an hour of their time.

It is worth acknowledging the limitations and drawbacks of our approach and our reported early results. Through our iterative and collaboration design process, we found that lesson design and development was a time-intensive process. Creating well-balanced lessons that are both engaging and challenging for non-experts was especially demanding. The authors of this paper were the lead developers of the Gateway Lesson and we found that we could not directly use ‘tried and true’ lessons and examples from our teaching portfolios. Rather we had to adapt and revise them to fit within the technical and pedagogical constraints of the Hour of CI lesson framework. Early results suggest this heavy effort did create an engaging and challenging lesson. Despite positive results, we acknowledge these are early results and lessons are still in development so we cannot assess the impact of the entire suite of Hour of CI lessons yet. Finally, it is important to note that the pilot program started in Spring semester 2021 in the midst of the Covid-19 pandemic. We do not have the means to test whether our early pilot results may have been impacted under this extreme circumstance, but it is worth noting as an extraordinary circumstance for reproducibility and replicability purposes.

Our next steps include continuing building the remaining lessons, refining our lesson design process and lesson developer guidance, continuing with the pilot program, and implementing suggested refinements. As noted above, early results suggest the need to reach out to learners at two-year institutions to ensure we achieve the intended institutional diversity. Further analysis is needed to understand any underlying trends in learners reporting the lesson as being too challenging or not challenging enough.

In summary, early results from our pilot program suggest that we are making progress toward achieving our key objective that the Hour of CI project can reach a broad and diverse audience of learners with engaging and useful learning experiences.

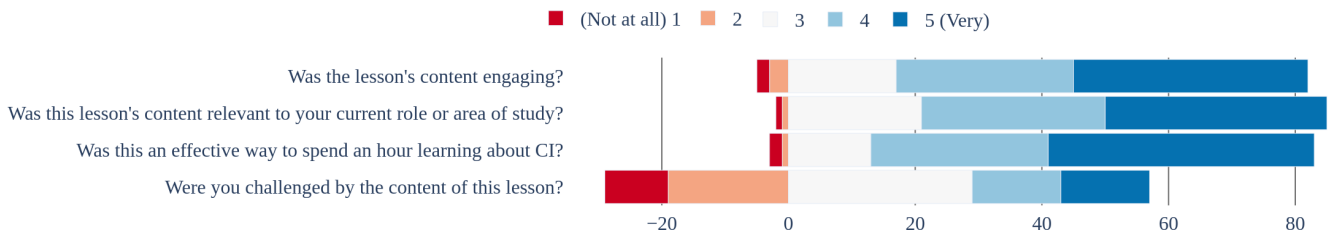

Fig. 5. Post-lesson survey responses using a 5 point Likert scale ranging from "Not at all" (1) to "Very" (5).

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