Project Description

Collaborative Research:

Diversifying Human-Centered Data Science through the Research and Design of Ethical Games

Introduction

Data science and artificial intelligence have influence over nearly every aspect of our modern lives. Going well beyond the private sector, these technologies are also deployed broadly in schools, government agencies, and academic institutions. Powered by this ubiquity and alluring performance results, many still believe that these algorithmic systems and the data on which they are built are objective with neutral norms and assumptions. The problems with data science practice and algorithmic data systems in their current form reveal themselves as these systems are used in increasingly disparate contexts. Marginalized populations have been found to endure a disproportionate amount of harm in facial recognition, natural language processing, criminal justice, and other applications (Sweeney, 2013; Bolukbasi et al., 2016; Buolamwini and Gebru, 2018; Noble, 2018).

The ethical and societal implications of science and technologies have been of interest to many social scientists, philosophers, engineering ethicists, and human-computer interaction researchers well before the artificial intelligence and software engineering communities have shown interest. Many of these more socially-aware fields are born of traditions that highly value contextual knowledge, critical analysis, and the understanding of power and organizational structures that deeply impact our understanding of the data. Data science, and particularly the fields of artificial intelligence and machine learning that dominate modern data science methodology and culture, regularly fail to account for these aspects of the data. **Human-centered data science** (HCDS) is an emerging field that bridges the gap between computational data science methods and the socio-behavioral nature of many modern problems that utilize data collected from the internet and personal technologies (Kogan, 2020).

Ethical simulation games, like the field of human-centered data science itself, appear to naturally provide tension between the techniques, culture, and norms of the social sciences and data science as well as promote minority student participation in research. In the creation of such a game, student designers must continually balance the contextual awareness and speculation with computational feasibility and algorithmic limitations. By studying student researchers undergoing this design process, we gain insight into how conflicts in norms and culture change the learning process. Collaborative game design is also an ideal activity to encourage minority student participation in scientific research and STEM fields (Simons, 2016, 2020). Increasing diversity is particularly important for artificial intelligence, data science, and computing given the concentration of power in the field as well as the connections it is found to have to the broader ethical and social failures in these fields (Kuhlman, Jackson, and Chunara, 2020).

Our proposed research project studies learning in the face of increased diversity as well as conflicting methodological cultures in three ways. First, it invites interested undergraduates across disciplines to collaborate on the research and design of a serious game on data ethics issues. Participating students will come from two university campuses in different regions of the United States to form a single team of diverse individuals, supervised by PhD students and faculty and connected via internet technologies. By studying students' experiences throughout the project, we will increase our understanding of learning through collaboration in diverse teams and in areas of conflicting norms. Second, it brings together a senior faculty researcher from the University of Washington (UW) with an early career data science researcher at the same institution and a junior faculty member at the University

of North Texas (UNT), a designated Hispanic-Serving Institution (HSI). Through this collaborative team of women, two of whom come from communities that are underrepresented in STEM, there will be an increased capacity for conducting high quality research with diverse participation. Third, the end product of this two-year, interdisciplinary project will be a game, targeted towards underrepresented communities, that will bring more people into critical conversations about the roles of AI and data science in our society.

Our project is designed to answer the following research questions:

1. How do students individually and collectively position themselves within data ethics and do these views change over time with increased exposure to technical concepts and norms?
2. Does the collaborative design of an ethical simulation game facilitate diverse student learning experiences? If so, how does this inform theories on the science of learning in environments with conflicting norms?
3. In what ways do underrepresented students see their personal relationship to the fields of data science, data ethics, and game design in the periods before, during, and after working on a related research team?

Background

Collaborative Learning and Identities

In studying collaborative learning, researchers center social practices in the development of knowledge. In Jean Lave and Etienne Wenger's book, *Situated Learning: Legitimate Peripheral Participation* (1991), the authors shifted the analytic focus of learning from the individual to collaborative activities. Legitimate peripheral participation "refers both to the development of knowledgeably skilled identities in practice and to the reproduction and transformation of communities of practice." (Lave & Wenger, 1991, p. 55) Using apprenticeship situations as examples, these authors defined learning as increasing participation in communities of practice. Unlike the stereotyped “master-apprentice” dyad, these settings have a number of apprentices who are progressing through several series of skill-based tasks of increasing difficulty and importance to the enterprise. Peer circulation of information plays a major role in helping learners move along the continuum towards becoming a “master.” There is no center in the community, but the "centripetal development of full participants" as newcomers eventually become and replace "old-timers" (Lave & Wenger, 1991, p. 57). Identity is significant in this theory, in which learning "implies becoming a different person with respect to the possibilities enabled by these systems of relations" (Lave & Wenger, 1991). The power of situated learning as analytical perspective is that it enables us to see that learning does not occur in the abstract, but learning is situated in a context with sociocultural-historical practices that shape individual cognition.

Lave, Wenger, and many other researchers (Nasir, 2011; Wortham, 2006; Romaine, 2009) view the role of identities as “a critical mediator of learning" (Nasir & Hand, 2006, pp. 467-468). Dorothy Holland and Kevin Leander (2004) expound on the theory of identity and positioning in their introduction to an *Ethos* journal issue dedicated to the topic. They define positionings as "pivotal moments in which social and psychological phenomena come to interanimate and interpret one another" (Holland & Leander, 2004, p. 127) which "involves socially producing particular individuals and groups as culturally imagined types such that others and, even the person herself, at least temporarily, treat her as though she were such a person" (Holland & Leander, 2004, p. 130). For example, a child is positioned as a particular

kind of student, such as “smart” or “slow,” by the various ways in which her teacher and her peers interact with her each day. Through experiences, thoughts, and repeated positioning moments occurs a "thickening" of identity, as first described by Dorothy Holland and Jean Lave (2001) and expanded on in the work of others, most notably Stanton Wortham in his school-based research (Wortham, 2004, 2006). Holland and Leander use the metaphor of "lamination" to describe the identity created through mediated activity, pointing to how each layer in the lamination process may maintain visible characteristics. Our past identities don't leave us, but become part of an evolving "social/psychological" entity.

Another important question when studying collaborative learning is what keeps the individual learners active in the group. Flávio S. Azevedo (2011) conducted a three-year-ethnography of model rocketry hobbyists to deepen the understanding of persistent engagement in individual interests. He defines a "line of practice" as "a distinctive, recurrent pattern of long-term engagement in a person's practice participation." (Azevedo, 2011, p. 147) Within the line of practice are two structural elements that define an individual's activities; preferences, which are "deep, long term goals, values, and beliefs that a person develops in the practice", and conditions of practice, which are "the constraints and affordances impinging on the person’s practice", such as access to required resources or relationships with fellow practitioners (Azevedo, 2011, p. 147). Previous theories about interest pursuits centered on the individual’s relationship to the content of the activity. While connection to this domain does play a role in persistent engagement, Azevedo found that "a person's extended participation in a practice follows from the continuous satisfaction of various parallel and interacting motives that he/she develops in the practice" (Azevedo, 2011, p. 179), such as spending time with friends and family members or enacting a particular identity.

A learner’s motives for collaborating in a team scenario are likely to shift over time. Mimi Ito’s ethnographic research into youth media engagement across settings uncovered three levels of participation with differing imperatives. Also known as “HOMAGO,” each represents an increased level of involvement: 1) “hanging out” and using media for social reasons, 2) “messing around” with media to develop skills based on interests, and 3) “geeking out” by developing expert digital skills in an area of specialization (Ito, 2010). Ito and other researchers with a sociocultural lens and commitment to equity built upon this research to create the “connected learning” framework for education research and design (Ito et al., 2013). This framework aims to address gaps between in- and out-of-school learning, particularly broadening participation for non-dominant youth in rich extended learning spaces. Connected learning contexts feature interest-powered learning, peer-supported experiences, and an academically oriented outlook. The most effective connected learning experiences are shown to be openly networked beyond the immediate venue, production/creation centered, and offer a shared purpose within cross-cultural and/or cross-generational groups.

Data Science Norms and Tensions

Data science and machine learning practices have raised numerous ethical concerns with regard to problem formulation, bias, harm, inclusiveness, and diversity of the community. Despite the rapid increase in awareness and research on these topics, there are still many computational researchers who dismiss the relationship of concerns of algorithmic bias and other human-centered concerns to the norms, assumptions, and methods in their field. Social scientists Moats and Seaver reflect on several points of normative commitments causing tension between data scientists and the social scientists who study them (2019). In psychiatry, Stevens, Wehrens, and de Bont introduce the notions of “epistemic virtues” and

"trading zones" to describe normative differences between data science and psychiatry and how those differences are negotiated (2020).

This tension can also be found within data science itself—often between traditional data scientists and those who are more human-centered, or alternatively, more methodologically rigorous. One such example sparked public debate between Dr. Timnit Gebru and ACM Turing Award Laureate Dr. Yann Lecun regarding his claims that racial bias in an image upsampling model were due to dataset bias to the exclusion of embedded biases in the models and methods of the field (Kurenkov, 2020). This was one of many instances that showed cultural and normative differences between human-centered data scientists and traditionalists of the field. The propensity of data scientists to tackle ethical and societal questions with little domain knowledge, without reference to the previous bodies of work in the social sciences, and to the tune of much higher salaries are other issues that build on this tension. Critiques of the methodological norms and rigor also come from within the data science and machine learning communities (Malik, 2020; Lipton and Steinhardt, 2019). Many of these tensions are attributed to the differences between the statistics and computer science communities.

As a sign of lessening tension, computer scientists in the ethical AI space have embraced human-centered ideas from other fields. Workshops and tutorials on participatory design have been well-attended at computer science and machine learning conferences such as the International Conference on Machine Learning. Ms. Herman is a co-author on two relevant studies analyzing the context and outcomes of a participatory design process while creating an algorithmic equity toolkit for largely non-technical community activists (Krafft et al., 2021; Katell et al., 2020). Conferences, including those that are overwhelmingly technical and theoretical, have included workshops and research tracks related to data ethics and fairness in machine learning. Other data science conferences and venues have instituted an ethical impact statement with all submissions, though those submissions have left much to be desired (Boyarskaya, Olteanu, and Crawford, 2020).

Serious Games

Although known for their popularity with youth, games, in a variety of forms, are played amongst people of various age groups and cultures. Playing a game involves affect, be that a sense of fun, a feeling of frustration, or the pride of accomplishment. When played together, game experiences can create bonds between players, especially when working collaboratively. Our affective experiences impact our learning, and games have been shown to positively impact learning gains. As a way of deepening learning, and increasing interest, a number of researchers and educators have created game design activities as a part of a range of curricular topics. Given the ubiquity and popularity of games, we can use them to widen participation in conversations about AI and data science. Games hold particular promise for exploring ethics, a subject that has proven particularly difficult to frame in classroom settings and transfer across situations. To widen these conversations about algorithmic ethics, we must create spaces where diverse minds can come together and collaboratively develop expertise in navigating tensions between ethics and computation.

In game studies and digital media literature, the "magic circle" refers to a metaphorical bubble that encapsulates play in a virtual world where players are governed by different rules than those of the natural world. In the context of ethnography, anthropologist Gary Marcus proposed the para-site which serves a similar function: "a site of alternativity, in which anything, or at least something different, could happen" (2000, pp. 8). Speculative fiction approaches to data ethics benefit from the freedom of the magic circle but are not well equipped to address technical computational and methodological

approaches. Digital games are an ideal complement to this work, as they can easily simulate with the computational and statistical methodological choices more aligned with the day-to-day work of graduate students and early researchers.

As a learning tool, games offer a context in which abstract concepts can be made relevant to participants (Dieleman and Huisingh, 2006; McGonigal, 2011). Whether a researcher focuses on expressly designed education or "serious" games or choose to examine skills and knowledge gained from entertainment games, the fact remains that to play is to learn (Bodrova & Leong, 2015; Holzman, 2009). The increased availability of digital games to all demographics has led to increased scholarly attention on what games offer learners. These researchers provide evidence of a number of positive impacts of game play in a variety of settings (for example, Gee, 2013; Ito, et al 2019; Kafei et al 2016). For example, a critical literature review demonstrated that digital narrative-driven games create higher rates of attitude change among learners, compared to traditional instruction (Jackson, et. al, 2016).

Methods

In this study of learning, we will apply sociocultural-historical theory, as it is well-suited to the examination of collaborative work. Sociocultural-historical theory, most commonly associated with Russian intellectuals from the early 1900's, particularly Lev Vygotsky, posits that "the structure and development of human psychological processes emerge through culturally mediated, historically developing, practical activity" (Cole, 1996, p. 198). From this perspective, previous and contemporary research has illuminated the relationship between identity and learning (see Lave & Wenger, 1991; Nasir, 2011; Bell, et al., 2012).

Sociocultural-historical theories offer a powerful approach for understanding the relationship between multiple levels of phenomenon. Barbara Rogoff describes three different ways to view processes analytically that are actually "ongoing, mutually constituted" (Rogoff, 2003, p. 52). Any activity is made of *cultural-institutional*, *personal*, and *interpersonal aspects*, but to understand a situation, ethnographers focus on one of these aspects at a time by foregrounding certain pieces. Rogoff writes, "It is usually necessary to foreground some aspects of phenomena and background others simply because no one can study everything at once. However, the distinctions between what is in the foreground and what is in the background lie in our analysis and are not assumed to be separate entities in reality." (Rogoff, 2003, p. 58)

As we humans move through our daily lives, we typically focus on the moment-to-moment experience. Even in an ethnographic study with a large data corpus, researchers capture only a slice of what happens in the lives of our participants. Maintaining a sociocultural-historical outlook reminds us that histories are attached to the moments experienced. This is especially important when studying the learning experiences of underrepresented students, whose family histories include many individuals kept out of STEM education and careers.

Because we want to better understand how underrepresented students view themselves over time in relation to the field of data science, our research method of choice is an ethnographic case study. Qualitative methods, particularly ethnographic analysis, explore the multiple meanings and features of a complex context. By implementing a case study, we focus the attention on how participants construct meaning and view themselves in relationship to and as part of a collaborative research team (Merriam, 2009, p. 14). Taking this approach calls for attention to the following: means and contexts of

communication and information transfer, historical developments, and adapted practices and activities as students interact with each other and the leaders of the group. Congruent with a sociocultural-historical perspective is the need to focus on social interactions as they occurred in combination with participants' narratives of their practices. In addition to observing activities and practices generally, we will attend particularly to the use of language in the setting and the achievement of meaning gained through communication among the participants. In this study, language is taken as being key within the sociocultural-historical perspective (Cole, 1996).

Common to ethnographic methods, multiple streams of data will be collected over the course of the project, including observations in the "field," i.e. of the team meetings (consisted of both audiovisual recordings and researchers' field notes), informal conversations with participants, products created by the team (such as papers, images, prototypes, etc), brief surveys, and participant interviews. Data analysis, via the constant comparative perspective (Heath & Street, 2008), will begin during the study with iterative reviews of the research literature, examination of theoretical constructs, and analysis of the data collected. Throughout data collection, we will write conceptual memos about discoveries, create analytic questions to further investigate the data, and build metaphors and concepts (Merriam, 2009, pp. 170-173) that explain patterns emerging from the research.

Project Plan

Year 1

The project begins in January because the start date of classes at each institution will be only a week apart, instead of the month date separation in the Fall term. This enables the student teams to begin working together as soon as possible. Prior to the beginning of classes, researchers will hire two PhD students. The doctoral student at the UW will co-lead the entire undergraduate team in year one with a doctoral student at UNT. The selected graduate students will have content knowledge in at least one of the relevant disciplines as well as some prior experience in leading work groups and/or classroom instruction. In each case, a student of color will be given preference for selection. At their start date, we will onboard the PhD students, giving instruction about the research project as well as soliciting their thoughts and suggestions. This will encourage project ownership for the PhD students and establish a research mentorship relationship with the PIs.

In the academic term prior to the start of the project, the PIs at each institution will advertise a special topics course for undergraduates, describing it as a unique opportunity to learn about research, data science, data ethics, and game design. The course will require a two year commitment and a willingness to be a research participant in our study of the science of learning. We will prioritize the inclusion of students of color and other underrepresented students at each institution and all majors will be accepted, as long as the student has an interest in the relevant topics.

The first year will be devoted to establishing a productive working environment and sense of teamship across the two campuses and developing student content knowledge. This will include weekly meetings in which we will discuss relevant readings, brainstorm potential research models, and test various game types together via internet technology. As work progresses, students will also meet regularly in small work groups to focus on a set of tasks related to the larger project work. Dr. Aragon has much experience creating successful student research teams, thus she can provide an instructive model for Dr. Evans and Ms. Herman as emergent scholars. The three PIs will also coach the two PhD students in curriculum, instruction, and leadership with undergraduate researchers. By the close of the first project

year, the undergraduates will have a thorough grounding in the methods and ethics of data science and principles of game design for learning, as well as developed a cross-institution collaborative relationship.

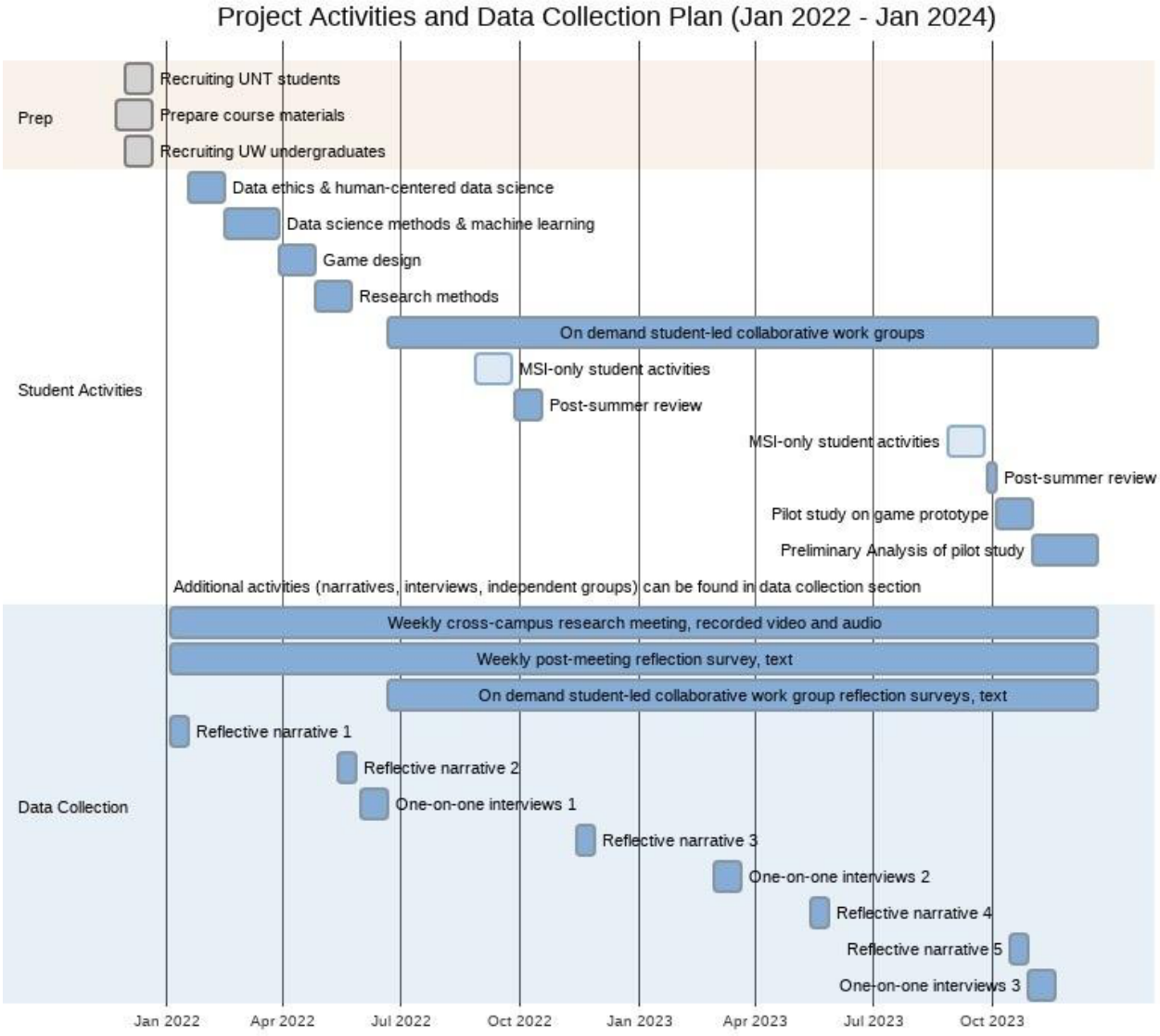

Figure 1: Project activities and data collection plan.

Year 2

At the transition to year two, the PhD student at UNT will take over supervision for the whole team of undergraduates at both institutions, now that their collaborative ties have been solidified. This will enable the student and faculty at the MSI to continue building leadership skills in the context of research teams. The team's primary focus for year two will be on designing and prototyping a game. The type of game and target age group will be established by the students themselves, but they incorporate data science methodologies and prioritize players whose identities are currently underrepresented in STEM. As part of this process, the student team will also develop research plans related to their game designs. By the close of the second project year, the undergraduates will have created a prototype of the game and completed an initial round of testing with the target audience.

Data Collection

Data will be collected at various points throughout the project. Prior to the beginning of the course, a private communication and document sharing system will be established to give the team a virtual space to interact with their peers and facilitate their work together. This will also create an ongoing record of team interactions. Before the first team meeting, each student will be required to write a reflective narrative about their experiences with games, data science, AI, and/or research. This exercise will be repeated at 6 month intervals, with students being asked to reflect on changes in their knowledge, skills, and attitudes towards these subjects over the previous interval. These reflections will be stored in a manner compliant with both institutions' human subjects review board and be accessible to the PIs and PhD students only.

Due to the geographic separation, all team meetings will be conducted weekly via internet-based meeting software, through which each session will be recorded, including audio, video, and chat logs. These recordings will be available to the undergraduate students to refer back to during the life of the project. At the close of each weekly team meeting, the students will complete a brief electronic form with the prompt, "Today, I…" and instructions to "Check all that apply." The items for selection will include statements such as "felt like a data scientist" and "understood the majority of terms discussed." The list of statements will be finalized in cooperation with the two PhD students, as part of their project onboarding. This weekly survey of the undergraduate students will provide a regular measure that can provide insight into the learning journey.

As the project progresses, students will form task-based work groups that will be expected to meet outside the full team meetings. Unless the work group specifically requests it for instructional purposes, the PIs and PhD students will not be present in the meetings. For each of these meetings, we will request the work group write and submit a brief paragraph that answers the questions 1) what decisions were made today? 2) what tasks were assigned and to whom? and 3) what additional information and/or resources does your work group need? The answers to these questions will serve both a pedagogical and a research purpose by providing a record of collaborative effort that can be compared and contrasted between the various work groups.

In addition to the four written reflections, each student will be individually interviewed by one of the PIs at least three times during the project. The conversational nature of these semi-structured sessions will provide another type of view into the students' learning process and identity shifts over time. It also allows the investigators to ask questions related to emergent patterns in the data corpus. These sessions will be recorded and transcribed, then made available in a secure manner to the PIs and PhD students for analysis and discussion.

In year two, as the undergraduates progress in designing the game prototype, the team will review research models. Together, the PIs and students will develop research questions and plan appropriate data collection methods to be used while testing the game with volunteers. In this way, the undergraduates will continue to develop their empirical research skills, which can be applied across domains as the move forward in their education and careers.

Nature of Partnership and Investigator Roles

Minority-Serving Institution: University of North Texas

Sarah Evans, the Lead PI, holds a PhD in Learning Sciences and Human Development from the University of Washington. During graduate school, she brought her expertise in the science of learning to a student research team under Dr. Aragon. This team investigated learning in online fanfiction communities, resulting in a new theory called "distributed mentoring" (Campbell, et al., 2016; Evans, et al., 2017) Inspired by this theory and its impact on students at all levels, Dr. Evans has continued collaborating with Dr. Aragon post-graduation. Now, as junior faculty in Information Science, she wants to build on Dr. Aragon's model for creating productive research teams and apply it to the ethics of artificial intelligence and data science through game development at UNT, a Hispanic-Serving Institution. Having an already established collaborative relationship, Drs. Evans and Aragon know how to share the work that goes into any research study. They have collaborated extensively on publications and research projects, often remotely. Dr. Evans is familiar with traditional literacies of reading, writing, and speaking, while Ms. Herman and Dr. Aragon have expertise with game design and distributed mentoring as it applies to collaborative informal learning. As Lead PI, Dr. Evans will share equal responsibility with her Co-PIs for planning and execution of the research components and working with students. All three PIs understand the critical role of coordination tasks in successful project outcomes (Cummings & Kiesler, 2007).

Non-Minority-Serving Institution: University of Washington

Cecilia Aragon brings her expertise in human-centered data science, serious games, and distributed mentoring to the project. She also brings decades of experience and passion as a mentor to members of underrepresented groups in STEM fields. Dr. Aragon will share responsibility with Dr. Evans and Ms. Herman for planning and execution of the research components and working with students. She will hire and mentor the Graduate Research Assistant focusing on these areas. As well, Dr. Aragon will participate in the dissemination of research, via presentations at meetings/conferences and formal publications.

Bernease Herman brings several years of experience as a data science methods, computational ethics in machine learning and data science, and game development to the project. She has also led multiple game design projects involving diverse groups of undergraduate students. She will share responsibility with Drs. Evans and Aragon for planning and execution of the research components and working with students. She will assist with mentoring the Graduate Research Assistant focusing on these areas. As well, she will participate in the dissemination of research, via presentations at meetings/conferences and formal publications.

Intellectual Merit

Much of the research on data science education and learning focus on integrating ethics and societal understanding into the curriculum of data and computer scientists. Given the relative power of computer science and STEM departments, this is a worthy cause. The topic of data ethics has been regularly covered in the public media with news cycles fueled by new research findings, initiatives by well-known technology companies and organizations, as well as public incidents and new discoveries of societal harm. Researchers report that public reporting on these areas is widely disseminated, but discussion of the underlying power and societal issues is shallow (Ouchchy et al., 2020; Barn, 2019). There has been an explosion of efforts to introduce pedagogy for data scientists that furthers their understanding of the ethical and societal implications of their work. Yet such efforts must be based in a

holistic understanding of how learners move along varied pathways in pursuit of subject knowledge. When seeking to broaden participation, an understanding of learning that accounts for sociocultural and historical influences becomes critical to successfully engaging diverse participants.

Our project addresses these issues through an innovative combination of three related fields of study. Human-centered data science brings a socio-behavioral lens to examine the impacts of data collection and usage in modern communities. Similarly, the learning sciences shifts the focus from individuals as self-contained learners to explore the collaborative learning practices shaped by society, culture, and history. In recent years, these researchers have brought their understanding of learning as situated to explore the role of data in various educational settings. The socially responsible focus of these two fields find a natural complement in the study of serious games.

The collaborative design of a data ethics simulation game requires students to regularly confront tensions between the contextual understanding of data in ethics and human-centered fields with the assumptions of objectivity embedded in purely computational fields. Prior serious games in data ethics do not emphasize this tension and focus on only one of moral responsibility or teaching methodological concepts. This project leads the way in using the simulation game as a unique tool to inform the science of learning under conflicting norms. Our work also seeks to identify factors that enhance the experiences of underrepresented people in data ethics and contribute to the knowledge of STEM learning benefits and barriers for students of color. By involving participants from communities of color, who have traditionally been shut out of conversations on science, we can find new ways of thinking about artificial intelligence and its ethical implications in collaboration with people likely severely impacted by uninformed design.

Broader Impacts

The project advances diversity in data science in both its execution and its repercussions. First, a diverse group of undergraduates from two regions of the United States will be immersed in STEM. This model of research collaboration allows for the creation of new knowledge that takes into account underrepresented perspectives. Second, the designed game will specifically be targeted towards participants currently underrepresented in STEM fields, thus pulling diverse voices into conversations about ethics and artificial intelligence. Third, this project is conceived, designed, and will be implemented by an all-female research team that includes a Latina professor and a Black data science researcher. Our collaboration serves as a model for women who also want to conduct meaningful research in the STEM fields. The partnership also builds the research capacity of a junior faculty member and a PhD student at a Hispanic-serving institution through the mentorship of an experienced senior faculty member at a prestigious research institution. The result will be additional research opportunities for a diverse student body.

Results from Prior NSF Support

Cecilia Aragon was the PI for CI-TEAM Demo: Collaborative Games for Bioinformatics Education of NSF award #1135479; Amount: $250,000; Award Period: 10/1/11-9/30/14. This project applied the socio-emotional mechanics of online collaboration and multi-player games to create a novel educational game, Max5 (Perry et al., 2012b). **Intellectual merit** includes empirical and conceptual contributions to research in educational game development and the educational component of data science

and bioinformatics. **Broader impact**: Max5 has been played by over a hundred high school students in multiple classrooms in schools with some of the most diverse populations in Seattle. The long-term benefits include (i) the concepts of cyber problem solving among a diverse group of young people, including underrepresented minorities and women; and (ii) the production of conceptual models that help better understand the larger relationships between and the sociotechnical systems involving people, educational games, and computational technologies. Multiple publications have been produced (Perry et al., 2012a, 2012b; Perry and Aragon, 2012; Perry et al., 2013a, 2013b, 2014).

Sarah Evans has not received prior NSF support.

Bernease Herman has not received prior NSF support.