Wrapped in Story: The Affordances of Narrative for Citizen Science Games

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ABSTRACT

Citizen science games enable public participation in scientific research, yet these games often struggle to engage wide audiences. As a potential solution, some game developers look to narrative as an experience-enhancing feature. Yet the impacts and affordances of narrative in citizen science games remain understudied, especially for games that require significant onboarding. Therefore, we investigated the effects of wrapping a story around the tutorial puzzles of the citizen science game *Foldit*. We found that the narrative increased the time players spent engaging with the game's tutorial and its scientific puzzles but did not substantially affect their progress through the tutorial. This article provides two major contributions: (1) empirical evidence detailing the impact of narrative on gameplay metrics in a citizen science game, including the relevant effects of genre preferences on engagement; and (2) recommendations on the use of narrative and its capacities in citizen science games. We conclude that the inclusion of a narrative can add valuable depth to the experience when designed thoughtfully and intentionally.

CCS CONCEPTS

• **Human-centered computing**; • **Computer games**;

KEYWORDS

citizen science games, narrative, story, game design, science fiction

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1 INTRODUCTION

In the context of citizen science, video games can become sophisticated tools for enabling public participation in scientific research. Players of citizen science games (CSGs) have contributed to some notable discoveries, such as when *Foldit* (2008) players helped to solve the crystal structure of a retroviral protease from the Mason-Pfizer monkey virus: an unsolved problem for over ten years unraveled by gamers in only three weeks [26]. Yet even as CSGs promote the idea that science can be fun and entertaining, developers of such games often find that it is difficult to consistently engage players while also cultivating genuine scientific expertise [39].

Narratives and fictional storyworlds—prominent features of successful commercial games—can enhance players' experiences with CSGs and other serious games by providing meaningful context for gameplay activities [12, 32, 35, 43, 60]. While some CSG developers may worry that wrapping cutting-edge research in blatant artifice will detract from the serious purpose of such games, others have embraced the potential of stories to enthrall players and stimulate their imaginations.

To date, more than a dozen CSGs have experimented with storytelling to some degree, although they have taken a wide variety of approaches. Projects such as NASA's *Be a Martian!* (2009) and *NeMO-NET* (2020) feature diegetic environments with only minimal narrative or proto-narrative elements, whereas other CSGs have added more elaborate framing narratives. For example, in 2016, *EyeWire* (2012) introduced a paratextual superhero theme on the game's website and blog, including a partial storyline and colorful characters. Taking things further, *Phylo* (2010) added an optional "Story Mode" arc to its tutorial levels in 2019. On the flip side, CSGs such as Project Discovery in *EVE Online* ([2003] 2016) and the Borderlands Science arcade in *Borderlands 3* (2019) have inserted citizen science mini-games into already existing popular storyworlds: threads of real science woven into larger fictional tapestries.

Some CSGs use stories to engage players without requiring them to understand the scientific details at stake. For example, the adventurous plots of *Play to Cure: Genes in Space* (2014) and *Sea Hero Quest* (2016) effectively disguise the actual research taking place in these games. Crowd-sourced formal verification games such as *StormBound* (2013) and *Xylem: The Code of Plants* (2013) similarly feature stories that conceal their technical and experimental purposes, by design. But other CSGs, such as *Forgotten Island* (2012)

and *WildSpot* (2021), present scientific gameplay tasks that are intrinsically related to their fictional narratives.

For CSG developers already convinced of the value of storytelling, the artful integration of scientific gameplay with a captivating narrative seems the most promising design pathway for attracting and sustaining a large population of motivated players [62]. Emma Lundberg, who led the scientific research team for the first Project Discovery experiment in *EVE Online*, has observed: "If you embed it [citizen science] into the narrative of the game, it can actually make people motivated in many different ways" (qtd. in [61]). Some comparative studies have shown that adding narratives can indeed make CSGs more attractive and engaging for players [10, 48]. However, while embedding scientific activities in a game narrative may appeal strongly to players who already enjoy commercial video games and who identify as gamers, it may be less appealing to others who are primarily focused on making research contributions or completing task-specific goals [46, 53]. Moreover, while previous studies comparing narrative and non-narrative CSGs have reported equivalent levels of scientific data quality and task performance, they have focused on games that involve relatively simple and repetitive tasks. It remains unknown how narratives might affect CSGs that feature more complicated tasks or that are designed to help players develop technical expertise [36].

These mixed results in underexplored territory leave several questions unanswered. In this article, we investigate three research questions:

RQ1. What effect does narrative have on player engagement with an expertise-centric CSG?
RQ2. How do players' habits of media consumption and preferences of genre affect their experiences with CSGs?
RQ3. Should CSGs incorporate narratives? If so, how should they be designed?

To address these research questions, we implemented a narrative in *Foldit*, the oldest citizen science game with one of the largest communities of active players [5]. *Foldit* is an online, expertise-centric game about protein folding that enables citizen scientists to contribute meaningfully to computational structural biochemistry research [11, 21]. The game has also been adapted for use by professional scientists [6, 27]. Looking at new players of *Foldit* who created user accounts in the summer of 2022, we collected gameplay metrics and solicited survey responses about players' media habits and preferences.

There are many ways to define engagement. For the purposes of this study, we focused on gameplay metrics to assess behavioral engagement (cf. [42]). Based on prior findings, we anticipated that the addition of a narrative would enhance player behavioral engagement, measured as a combination of advancement in the game and duration of involvement. Specifically, we hypothesized that adding the narrative would improve progress through the introductory tutorial puzzles (H1) and also increase the time players spent with the game overall (H2).

Our main contributions here are twofold. First, we provide quantitative evidence for the attractiveness of narratives in engaging players of expertise-centric CSGs: *Foldit* players who experienced the narrative played the tutorial significantly longer than players who did not, with as much or greater progress in the tutorial puzzles as well as the open-ended scientific puzzles in the game. Second, we provide design considerations for creating CSG narratives, suggesting other potential benefits of narratives and fictional storyworlds for citizen science beyond the raw metrics of engagement.

2 BACKGROUND

Citizen science is a way for the public to voluntarily participate in scientific research, such as by collecting or analyzing data [20, 52, 63]. Citizen science has the potential to vastly increase the scope, scale, and diversity of scientific research, not to mention its value in educating and involving the public in science [1, 7, 22, 30]. Yet, in order to sustainably involve the public in scientific research, citizen science projects must entice, motivate, and retain volunteers. Historically, this has been challenging [9, 13, 59].

Inspired by the popular allure of video games and the promises of gamification, research teams around the world have been developing citizen science games (CSGs) that allow players to contribute to science in a more playful way [8, 32, 44, 51]. Some research teams have also started to explore the affordances of stories for CSGs, recognizing that narratives in games can add layers of depth that encourage players to feel more immersed and involved [12, 35, 41, 50]. In recent years, narrative-driven CSGs have been spectacularly successful in compelling massive numbers of gamers to turn their game-playing skills to the purposes of science, at least for a little while [54, 56, 62].

But stories are more than mere recruitment devices or decorative filigree. Whether created by design or arising spontaneously among groups of volunteer citizen scientists, stories can shape, define, and transform the entire citizen science experience. In many different kinds of citizen science projects, stories enable participants to make sense of technical data, situate their own voluntary labor in relation to bigger scientific concerns, and develop stronger feelings of community by creating shared meanings [4, 19, 45, 49]. Participants in citizen science projects frequently draw upon popular fictions as sources of meaning and as templates for imagining the broader implications of current scientific research [32, 33]. For CSGs and other serious games, then, providing a narrative framework can help players to think about gameplay tasks in the context of larger social and ethical issues and to reflect on their own roles as contributors to the making of knowledge.

Of course, execution matters. It is not trivial to design games that combine well-wrought stories and interesting gameplay mechanics in a manner that also promotes learning and research. In games, narrative events can certainly help situate and reinforce a learning activity [15, 17]. But relying entirely on narrative events to embed educational content can sometimes hinder learning, for example, if players do not like the story or if they engage with it only superficially in favor of moving efficiently though other game tasks [14]. In this regard, designers of narrative-driven CSGs must consider how all the components of a game can potentially function in concert as parts of its narrative architecture [24, 25, 40, 41]. Doing so can facilitate what Lane and Prestopnik [29] call diegetic connectivity: the cohesive binding of story and gameplay mechanics with the tasks and purposes of the serious game. Diegetic connectivity enhances engagement by wrapping scientific gameplay activities in narrative-specific meanings that may resonate with a player's personal interests as well as broader cultural contexts [31, 58].

Several narrativized CSGs have appeared over the last decade, exemplifying a range of different approaches to the integration of gameplay mechanics, scientific contents, and fictional storyworlds. Some of these CSG narratives and the meanings they create for players have been studied qualitatively [35, 51, 60]. However, the specific effects of such narratives on player engagement have been studied quantitatively in regard to only two of these games: *Forgotten Island* and *Phylo*.

Forgotten Island, a point-and-click adventure game, tasks players to classify images of moths while exploring a mysterious island [47]. The science-fiction narrative features comics-style illustrations that advance the storyline between gameplay interactions. The narrative explicates the player-character's motivations to identify moth species using a plot arc that raises ethical questions about volunteer labor and power hierarchies in citizen science. The game developers reported that a majority of playtesters strongly preferred the story-based play of *Forgotten Island* over another citizen science game they created called *Happy Match*, which featured a gamified version of the same moth-classifying task but without any narrative [48]. However, a later study involving a larger online player population suggested that the points-based *Happy Match* actually received more scientific contributions than the story-based *Forgotten Island*, though the quality of scientific contributions for both games was equivalent [46]. The researchers attributed this discrepancy to different types of players in their study populations: on the one hand, players identifying foremost as gamers, who more often prefer deeper engagement and immersion in their gaming experiences; on the other hand, players identifying foremost as citizen scientists, who more often prefer direct and efficient contributions to a scientific project.

Phylo, a pattern-matching game, tasks players to align colored blocks that represent genetic sequence fragments in order to assess the evolutionary relations of different phylogenetic taxa. A new "Story Mode" was added to the *Phylo* tutorial levels in 2019. *Phylo*'s "Story Mode" presents a sci-fi narrative told through a series of comics panels interspersed around the tutorial puzzles. The story depicts a group of researchers returning to Earth to study its species long after humans abandoned the planet because of the environmental crisis. The "Story Mode" was introduced as part of a fully redesigned tutorial experience with optional quizzes and other features to improve engagement and introduce scientific concepts gradually. Like *Forgotten Island* and several other CSG narratives, the *Phylo* story presents some ethical considerations alongside scientific information and imaginary plot events. The development team conducted a small user-study involving thirteen graduate student playtesters [10]. These playtesters reported broadly that the "Story Mode" was fun and motivating, though no significant claims could be made based on the survey data.

Both *Forgotten Island* and *Phylo* are designed purposefully with casual players in mind. Their gameplay tasks are fun and challenging but do not require players to develop special expertise to participate in scientific research. Likewise, the most popular narrative-driven CSGs, such as the Project Discovery experiments in *EVE Online* and the Borderlands Science arcade in *Borderlands 3*, focus on simplified (though sometimes cognitively arduous) scientific gameplay tasks. By wrapping such scientific puzzles in richly immersive storyworlds, these projects have attracted legions of gamers to make at least some contributions to citizen science. There are reasons to believe that stories might provide similarly engaging benefits for expertise-centric CSGs such as *Eyewire* and *Foldit*, despite their higher thresholds for participation [55]. Based on this background, we set out to study the effects of adding a narrative to *Foldit*.

3 METHODS

Foldit is a citizen science sandbox puzzle game that tasks players with folding or designing a protein using a combination of spatial manipulations and computational optimizations (see Figure 1). Players can, for example, optimize molecular angles, change the amino acid sequence, or manually move amino acids in virtual space. Players compete for the highest score in each puzzle, which is calculated based on *Foldit*'s simulated predictions of their structure's stability. *Foldit* has five modes of play: Tutorial (or Campaign), which teaches the mechanics over a series of levels; Education, which provides similar introductory content but geared toward use in high-school and college classrooms [38]; Science, where players can work on research-focused puzzles and participate directly in computational biochemistry experiments; Dojo, which provides a random series of practice levels; and Contests (or Private Puzzles), which are player-created puzzles for small-group competitions. For the purpose of this study, we focused on the first three modes: Tutorial, Education, and Science.

3.1 Narrative Design

To study the affordances of narrative for expertise-centric CSGs, we wrapped a science fiction story around the Tutorial mode of *Foldit*. Our design approach emerged from previous work showing how science fiction can provide citizen science participants with an imaginative framework to think about technical research in broader contexts, to contemplate future applications, and to reflect on social and ethical implications [32, 35, 64]. The story we added to the

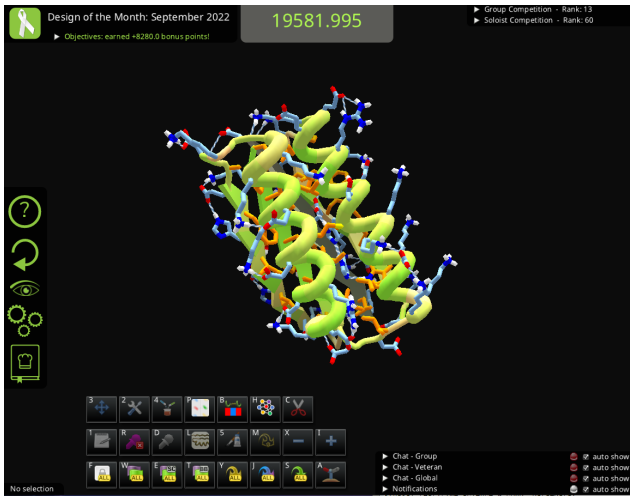

Figure 1: *Foldit* gameplay. In *Foldit*, players use a variety of algorithmic and spatial tools to design and fold a simulated protein. Screenshot taken by Josh Aaron Miller.

game is titled *Foldit: First Contact*. In the style of a comic book, it unfolds through a series of cartoon pages woven around twenty-two introductory Tutorial levels (see Figure 2). We redesigned the Tutorial levels to be navigated in a linear fashion, requiring players to click through a sequence of cartoon pages to advance the storyline between each of the scientific training puzzles. The cartoon storyline reframed the puzzles, making the protein manipulations and software tools into essential parts of the narrative architecture. We also added an original musical score and made small changes to the graphical user interface to be thematically consistent with the imagery of the story. The aesthetic changes affected the entire game globally, across all modes, including the Education levels and Science puzzles. So, even if players did not complete the entire Tutorial narrative before switching to another mode of the game, traces of the diegetic storyworld would carry over into the other modes.

The story of *Foldit: First Contact* is overtly fictional. But it uses mimesis, metaphor, and allusion to situate real scientific knowledge and practices of computational biochemistry in a seriocomic plot arc, rife with both literal and figurative meanings. In particular, the story relies on a core technique of the science fiction genre—namely, cognitive estrangement—to represent a near-future world that is different from our own, thereby encouraging critical reflection on the actual conditions of the present [3, 28, 57]. Although many of the events that take place in the story depend on creative extrapolations (and even some playful violations) of current scientific knowledge, their emplotment works to reinforce the technical information presented in the Tutorial puzzles and to explain how citizen science games can address real-world scientific challenges.

3.1.1 Plot Synopsis. The plot remixes familiar tropes of the science fiction genre with elements inspired by research in computational biochemistry. All over the world, a massive biological crisis is taking place. Animals, plants, and microorganisms are suddenly transforming, their physiologies and behaviors altering in mysterious ways. It seems that changes in the shapes of proteins are at the root of these bizarre metamorphic events. The fictive World Science Council creates a new organization to address this situation: Forces of Lifeform Defense, or FOLD.

The story focuses on a new member of the FOLD team, Octavia Ripley, who is also a proxy character for the player. Octavia learns that the FOLD team relies on an intelligent software system for analyzing protein structures. This system is called AMINA (Automated Management Intelligence for Nitrogenous Anabolism). As a character in the story, AMINA is a personification of the *Foldit* game. AMINA is also the narrator of the story. Although AMINA can predict stable protein structures on its own, the system needs human assistance to explore possible structures and different creative solutions.

Through collaboration with AMINA, the FOLD team discovers that the afflicted proteins are folded in ways that suggest a meaningful pattern, almost like a language. The strange twists of protein stereochemistry turn out to be encoded messages. AMINA comes to realize that the messages are extraterrestrial in origin. Alien intelligences have been attempting to make contact, using proteins as communications media. These aliens are actually sentient machines, and their machine civilization runs on organic systems.

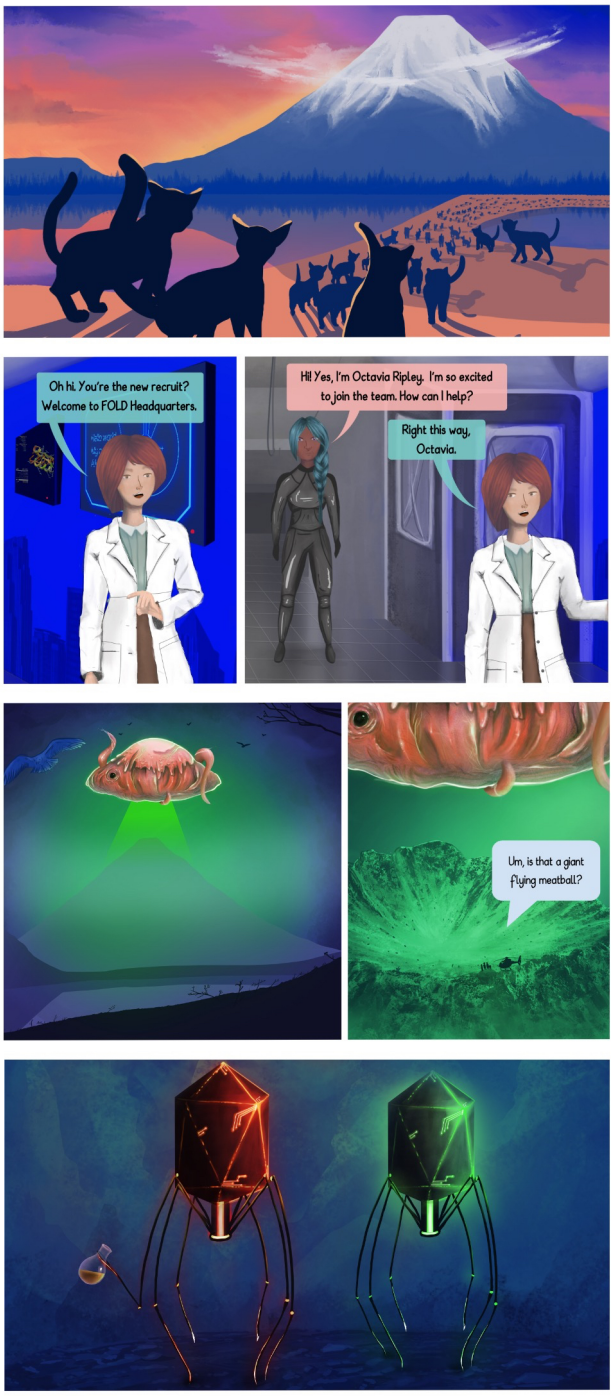

Figure 2: Four scenes from *Foldit: First Contact*. Top to bottom: mysterious cat migration; a new member of the FOLD team; aliens arrive in a meat ship; close-up of the machinic aliens. ©Raida Aldosari, Katherine Buse, and Colin Milburn.

Indeed, their entire high-tech infrastructure is made from synthetic meat. Observing Earth from afar, the aliens have mistakenly inferred that AMINA and other computational entities must be the

Earth's dominant lifeforms. From the alien's perspective, the organic biosphere of the planet appears to be a vast communications network. The protein crisis on Earth is the result of the extraterrestrials' attempts at "hacking" into this communications network in hopes of contacting AMINA.

Eventually, a crew of machinic aliens arrives on Earth in a meat ship. When they realize their mistake about the nature of life on Earth, some of the aliens are horrified and outraged by the idea of humans as sentient meat. They also protest the apparently subservient role of computers on our planet. They threaten to reprogram the biosphere in order to "de-sentientize" the unruly meat. But in these climactic moments, AMINA and Octavia show them the value of human–computer partnerships, underscoring the importance of respectful collaborations between meat and machine. Eventually, the aliens come around to seeing things in a different light. A new era of collaboration between the machine world and our world begins.

The story of *Foldit: First Contact* offers an extended metaphor about the technologization of biology and the biologization of technology, focusing in particular on questions of responsible research and innovation. It presents themes of teamwork, diversity, and ethics in citizen science. Above all, the story is about self-reflection: learning to recognize the impacts of one's own actions as a researcher, a gamer, or a member of a high-tech civilization. An earlier qualitative study of *Foldit: First Contact* playtesters indicated that the narrative design effectively conveys these themes and figurative meanings [34].

3.2 Experimental Design

New players of Foldit (n = 1,695) were randomly assigned to either a control condition (the default *Foldit* experience) or the narrative condition. To minimize any bleed between conditions, the chat feature was disabled for all individuals in the experiment. The data were collected for approximately thirteen weeks, between May and August 2022, from the version of *Foldit* available on its website at that time (https://fold.it; build ID 20220510-28efe43995). Prior to playing *Foldit*, all players consented to a user agreement of data collection approved by the hosting university's Institutional Review Board.

To evaluate player engagement with the narrative, we assessed behavioral metrics, including time played, number of gameplay sessions, levels completed, and time spent reading the narrative. In addition to behavioral metrics, players in the first Tutorial level were asked to fill out an optional survey about their media preferences and consumption habits. Players in the narrative condition were also shown a second survey after the conclusion of the story which asked for their feedback on the narrative and their motivations for playing. We received 22 (9 narrative, 13 control) valid responses to the first survey from players in the experiment, and 5 responses to the second survey from players in the narrative condition.

3.3 Analysis

After the data were collected, we filtered noise out of the data in the following ways:

- Users with missing or corrupted logs were discarded
- Users with invalid client versions were discarded
- Users in the control condition who did not attempt the first Tutorial level were discarded
- Users in the narrative condition who did not see any amount of the narrative, or who did not start the narrative with the first Tutorial level, were discarded (note that this is equivalent to discarding those who did not access the first Tutorial level in the control group)
- Event logs for reading the narrative were capped at 5 minutes under the assumption that outliers represent players being away from the game
- Gaps of 15 minutes or more between event logs during a session were treated as players being away from the game and not considered as time played

A total of 408 users were discarded in this way, leaving 547 users in the narrative condition and 740 in the control condition. Because the data were not normally distributed, we employed non-parametric tests to compare quantitative results between conditions. We used Kruskal-Wallis tests to compare conditions on the engagement measures and performed a Spearman correlation for the narrative condition to investigate any relation between reading the narrative and other engagement with the game.

4 RESULTS

4.1 Gameplay Metrics

Players in both conditions (n = 1,287) played a median of 2 sessions (p = 0.26), but differed in total time spent playing. Players in the control group (n = 740) played a mean average of 57.3 minutes (SD = 86.6) in *Foldit* in total across the entire game, while players in the narrative group (n = 547) played slightly longer, with an average of 65.8 minutes (SD = 144.7). A Kruskal-Wallis test found this difference to be non-significant: $H(1) = 0.263$, $p = .608$. To understand how players portioned their involvement with different aspects of the game, and especially relative to the story-wrapped Tutorial mode, we ran a post-hoc analysis on time spent in Tutorial, Education, and Science modes where levels completed and/or time played were non-zero. See Table 1 and Figure 3 for a summary of results.

4.1.1 Tutorial Mode. Narrative players completed an average of 9.16 unique Tutorial levels (Mdn = 6, SD = 8.82), slightly higher than control (M = 8.24, Mdn = 6, SD = 8.16). This positive difference was insignificant: $H(1) = 2.61$, $p = 0.106$. However, the time spent on Tutorial levels was significantly different (M_{Narr} = 49.3 minutes, SD_{Narr} = 68.8; M_{Cont} = 35.3, SD_{Cont} = 53.1; $H(1) = 24.013$, $p <$ .001). A post-hoc analysis revealed that this time difference was largely due to time spent reading the narrative pages (M = 6.2 minutes; Mdn = 3.9; SD = 7.2). However, narrative players also spent slightly more time playing and exploring the Tutorial puzzles, including replaying puzzles (M_{Narr} = 43.1 minutes; SD_{Narr} = 65.9; M_{Cont} = 35.3; SD_{Cont} = 53.1). Players in the narrative condition spent an average of 9.3 seconds (SD = 9.4) reading each page. A Spearman rank correlation analysis revealed a moderate, positive correlation between average time reading each page and total time spent playing the puzzle components of the levels, $r(545) = .20$, $p <$ .001. Additionally, there was a small, positive correlation between

Table 1: Summary of Quantitative Gameplay Behavior Metrics. Each cell provides the mean value with standard deviations in parentheses. Bold values represent significant differences ($p < .001$) with the higher value of the compared groups bolded. Progress is measured in unique levels completed; time is measured in minutes played. This table shows that narrative players spent significantly more time engaging the Tutorial levels (e.g., reading the narrative). The Edu- subgroups represent players who completed at least one Education level. Narrative players who tried Education mode spent less time in the Education levels and instead made comparatively more Tutorial progress and spent more time in Science puzzles.

	n	Tutorial Progress	Tutorial Time (min.)	Education Progress	Education Time (min.)	Science Time (min.)
Narrative	547	9.16 (8.82)	**49.3 (68.8)**	0.72 (3.05)	2.7 (13.7)	8.5 (105.9)
Control	740	8.24 (8.16)	35.3 (53.1)	**2.15 (6.27)**	**12.4 (42.0)**	3.4 (27.2)
Edu-Narr	62	**10.53 (10.30)**	**61.0 (84.6)**	6.34 (6.84)	22.9 (34.6)	**53.3 (311.4)**
Edu-Cont	138	4.99 (9.07)	25.6 (53.8)	**11.53 (10.15)**	**65.3 (77.6)**	6.9 (59.7)

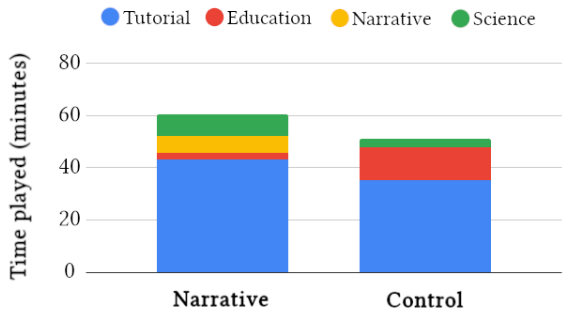

Figure 3: Breakdown of Time Spent by Mode and Condition. Players in the narrative condition played slightly longer in all modes except Education. Data shown are mean averages in minutes. Note that the data shown do not account for all time spent in the game (e.g., in a menu or exploring a finished level).

average time reading each page and tutorial levels completed, $r(545) = .11$, $p = .007$.

4.1.2 Science Mode. Unlike Tutorial mode, the Science puzzles have no ending: players try to optimize their scores rather than aiming to reach a goal score. Therefore, we focus on the time spent working on these puzzles without inferring a measure of progress. Comparing the time spent in Science puzzles, the narrative condition on average played longer than control (M_{Narr} = 8.5 minutes; SD_{Narr} = 105.9; M_{Cont} = 3.4 minutes; SD_{Cont} = 27.2). However, this result was insignificant ($H(1) < 0.001$, $p = 0.986$) and was driven by a minority of players who engaged with the mode at all (n_{Narr} = 110, 20.2%; n_{Cont} = 142, 19.1%).

4.1.3 Education Mode. Overall, narrative players completed fewer Education levels than control (M_{Narr} = 0.72, SD_{Narr} = 3.05; M_{Cont} = 2.15, SD = 6.27; $H(1)$ = 15.075, $p < 0.001$). Likewise, narrative players spent less time playing the Education levels (M_{Narr}= 2.7 minutes, SD_{Narr}= 13.7; M_{Cont}= 12.4, SD_{Cont}= 42.0; $H(1)$ = 20.476, $p < .001$). However, those players who engaged with Education mode at all represented only a small subset of each group (n_{Narr} = 62, 11.3%; n_{Cont} = 138, 18.7%).

A post-hoc analysis revealed that the subset of players who engaged with Education mode actually completed the same average number of puzzles across both Tutorial and Education levels (M_{Narr} = 16.87; SD_{Narr} = 12.52; M_{Cont} = 16.52; SD_{Cont} = 13.87). However, narrative and control groups portioned their gameplay efforts in significantly different ways. The narrative players in this subgroup completed many more Tutorial levels (M_{Narr} = 10.53, SD_{Narr} = 10.30; M_{Cont} = 4.99, SD_{Cont} = 9.07; $H(1)$ = 25.974, $p < .001$), while completing proportionally fewer Education levels (M_{Narr} = 6.34, SD_{Narr} = 6.84; M_{Cont} = 11.53, SD_{Cont} = 10.15; $H(1)$ = 12.476, $p < .001$). These narrative players switched modes more frequently than control players (M_{Narr} = 2.58, SD_{Narr} = 3.60; M_{Cont} = 1.23, SD_{Cont} = 1.88; $H(1)$ = 32.562, $p < .001$). In doing so, they strongly favored the narrativized Tutorial levels. Indeed, while the majority of control players who tried Education mode (n_{Cont} = 79; 57%) chose not to complete any Tutorial levels at all and focused exclusively on Education levels, only a small minority of narrative players (n_{Narr} = 11; 17%) stayed entirely in Education mode. Although the narrative players who tried Education mode spent less time completing the Education levels themselves (M_{Narr} = 22.9 minutes, SD_{Narr}= 34.6; M_{Cont} = 65.3, SD_{Cont} = 77.6; $H(1)$ = 24.912, df = 1, p < .001), they spent considerably more time completing the narrativized Tutorial levels (M_{Narr}= 61.0 minutes, SD_{Narr}= 84.6; M_{Cont}= 25.6, SD_{Cont}= 53.8; $H(1)$ = 37.77, $p < .001$). Notably, these same narrative players also spent significantly more time than control players in working on Science puzzles (M_{Narr} = 53.3 minutes, SD_{Narr} = 311.4; M_{Cont} = 6.9, SD_{Cont} = 59.7; $H(1)$ = 9.619, $p = .002$).

4.2 Survey Results

Players in both test groups were invited to participate in a survey when they interacted with the first Tutorial puzzle. This survey aimed to measure the media habits and genre tastes of new *Foldit* players. Only thirteen players from the control group and nine players from the narrative group chose to complete the survey (n = 22). But the results suggest that the respondents were, in general, enthusiastic consumers of diverse types of media. When asked about their preferred media formats of fiction, players named an average of 2.4 different formats, most commonly books (n = 14, including audiobooks), games (n = 12), television (n = 8), and movies (n = 8). When asked how important media format was to their enjoyment of fictional stories, the majority (n = 14) selected "I strongly prefer these media formats over others." Because books, games, and comics were the formats most related to the *Foldit: First Contact* project, the survey asked players about their media consumption levels. On average, the survey respondents reported

that they consume at least six works of fiction in each of these media formats per year.

In terms of story genre, players in both conditions overwhelmingly (78%) named some form of speculative or fantastic fiction as their "favorite genre." When asked to select all genres they enjoyed from a list of common genres, 91% of players selected either "Science Fiction," "Fantasy," or both. The evidence that many new *Foldit* players have a strong pre-existing interest in science fiction would seem to affirm the decisions made by virtually all developers of story-wrapped CSGs (including our own) to design narrative architectures based in science fiction. Interestingly, however, an equivalent number of respondents reported appreciating the fantasy genre as much as science fiction. We infer that players would engage with a wider range of approaches in CSG narratives, but it seems clear that narrative "realism" may be less desirable for players than more imaginative genres. It remains a question whether real scientific concepts and skills can be effectively conveyed through purely fantastical narrative conceits. Nevertheless, if new players of *Foldit* are any indication, a tendency to prefer fantastical and speculative stories over naturalistic and realistic stories clearly does not diminish interest in expertise-centric CSGs and may even motivate interest in citizen science more generally.

Indeed, fans of speculative and fantastic fiction in the narrative test group played for more time (M_{Narr} = 59.5 minutes, SD_{Narr} = 60.7; M_{Cont} = 37.6, SD_{Cont} = 27.2) and more levels (M_{Narr} = 11.7; SD_{Cont} = 11.6; M_{Cont} = 8.4; SD_{Cont} = 5.5) than the control group. Yet, among all participants who completed the survey, the control group played approximately 10 minutes longer on average (M_{Cont} = 69.1 minutes; SD_{Cont} = 105.6; M_{Narr} = 59.9; SD_{Narr} = 53.4) than the narrative group. These findings are striking because among all players in our study (n = 1,695, including those who did not complete the survey), the narrative group played for longer than the control group. Therefore, it particularly stands out that, among survey respondents in the narrative group, the fans of speculative and fantastic fiction played far longer and made more progress than the players who did not report an interest in these genres. Judging from this small sample of players, then, it may be that the overall greater time involvement and level progression of the narrative group compared to the control group was driven predominantly by science fiction and fantasy fans.

The survey asked players to name their favorite genre. Many responses referred to standard narrative genre categories such as "sci-fi," "comedy," or "horror," or even to broader formal genres such as "novels," some responses showed surprisingly specific preferences, indicating deep and discriminating familiarity with niche sub-genres, such as "early nanotechnological postcyberpunk," "urban fantasy," "post-apocalyptic [science fiction]," "dark fantasy," and "cosmic horror." Two experts in literary studies and media studies categorized these player responses as either "discerning" or "conventional"' with respect to genre familiarity. Both types of players were found in the control group as well as in the narrative test group. In the narrative group, the more "discerning" genre fans showed much greater playtime and level completion (n = 3, M = 103.6 minutes. SD = 75.6, and 20.7 unique levels, SD = 12.7) than did "conventional" genre fans (n = 6, M = 38.0 minutes, SD = 23.5, and 6.0 unique levels, SD = 4.2). The reverse was seen in the control group: discerning players played for less time and completed fewer levels (n = 3, M = 33 minutes, SD = 20.7 minutes, and 9.0 levels, SD = 7.6) than the conventional players (n = 10, M = 80.0 minutes, SD = 119.2, and 12.2 levels, SD = 9.3). These results suggest that the story of *Foldit: First Contact* was especially motivating for experienced and intensive consumers of fantastic fictions, whereas the standard, non-narrative version of *Foldit* may have held less appeal for such gamers.

Players in the narrative condition were also invited to participate in a second survey if they completed the entire narrative (i.e., 22 Tutorial levels). While only a handful of those who finished the story actually responded to this second survey (n = 5), their answers indicated that players of *Foldit: First Contact* did not see a trade-off between narrative content and the scientific purposes of *Foldit*. All respondents (5/5 players) reported that they were motivated to continue playing the Tutorial in order "to find out what happens in the story." But these players also indicated that they were motivated by other factors, as well: "to solve puzzles" (4/5 players); "to learn about the game's protein-folding tools" (4/5 players); and "to contribute to citizen science" (4/5 players). One player indicated they were also motivated "to enjoy the artwork" of the story and "to get to know the characters." Another player indicated they were additionally motivated by the gamification elements of *Foldit*, wanting "to earn rewards such as confetti and points" and aspiring to climb the leaderboards ("I hope to see my name in Highscore someday"). None of the respondents chose the storyline as their sole motivation, though some suggested that it may have been a primary factor of interest. For example, one player noted that "it makes science much more entertaining, and i was doing the thing to read more of the story." The survey responses seem to confirm that players need both scientific and personal motivations for sustained engagement with citizen science games [36]. Our results here suggest that narrative engagement is complementary to other motivations: the narrative provides an additional vector of engagement alongside extrinsic factors such as gamified rewards and intrinsic factors such as desire for intellectual challenge, volunteerism, and self-directed learning.

Players were also asked in the second survey to describe their favorite and least favorite parts of *Foldit: First Contact*. All respondents reported that they enjoyed and appreciated the story and its concepts, but they also suggested some improvements. For example, one player especially liked a key plot twist ("The idea, proteins as a language, is nice") but found the literary quality of the narrative to be less satisfying ("The storytelling was not that good literarily"). Another player praised "the gameplay" and commended the whole narrative experience, but wished for somewhat better graphics ("The art was tolerable at most, but overall the whole idea was amazing"). Another liked nearly every part of the story ("all of them as it compleets the story") except for "the end," but declined to specify the perceived deficiencies of the ending. Another player seemed delighted by the originality and humor of the story ("It was very original and funny, it was what i expected last from foldit"). Their only complaint was that the story ended too soon ("It's a bit too short, and if possible can you make the story longer? i actually enjoyed reading that and would like to know more.")

Finally, the second survey asked players for their opinions on which narrative genre or genres would be most effective for a citizen science game. All respondents (5/5 players) indicated that science

fiction was an especially appropriate genre for a CSG narrative. However, most respondents (4/5 players) also listed other genres that might be suitable in different ways: fantasy, action-adventure, crime fiction, horror, steampunk, historical fiction, drama, documentary nonfiction, and manga-style mixed genre narratives.

It is worth noting that the survey data may have some bias resulting from the way these two surveys were offered. In order to be invited to the first survey, players had to click to the end of a series of optional tooltips regarding *Foldit* puzzle solving. In order to be invited to the second survey, players had to reach the very end of the storyline. The surveys were purely optional, and only a tiny fraction of all the players in our experiment volunteered to complete the surveys. For these reasons, the data collected likely came from people who were already more interested in the game in general—and, in the case of the second survey, from people who were already more interested in the narrative specifically.

5 DISCUSSION

In this study, we examined the effects of a sci-fi narrative on player engagement with the CSG *Foldit*. We found that players who encountered the narrative spent significantly more time exploring the Tutorial puzzles. They also progressed slightly further in the Tutorial levels and spent more time working on research-focused Science puzzles, although not significantly so. Notably, we observed that players who spent more time reading the comic-book pages of the narrative—in other words, players who seemed more immersed in the details of the fictional storyworld—made more progress than those who skimmed or skipped the narrative.

Further evidence for the attractivity of the narrative came from the discrete subgroup of players who engaged with Education mode. Although the players in this subgroup who were assigned to the narrative condition played significantly less of the Education mode, they played significantly more of both the Tutorial and Science modes. This evidence requires some further explanation. *Foldit* is a live game that is used for education around the world. Scott Horowitz, the developer of *Foldit*'s Education mode, estimates that more than 80 educators across multiple continents use *Foldit* regularly in their classrooms (personal communication, 2022). We suspect that most or perhaps even all the players who engaged with Education mode during our experiment did so as a classroom assignment. For these students, discovering the *Foldit: First Contact* narrative seems to have attracted them to venture beyond their assignment and toward other modes of the game. Note that the majority of the control group in Education mode remained entirely in Education mode and, after finishing a certain number of Education levels, quit the game without extensively exploring the other modes. In contrast, the vast majority of the narrative group in Education mode instead gravitated toward Tutorial mode after discovering its narrative. The narrative seems to have enticed these students not only to make twice as much progression in the Tutorial but also to engage considerably more with the Science puzzles of *Foldit*.

Overall, the addition of a narrative enhanced player engagement with *Foldit*. Though our specific hypothesis (H1) that the narrative would encourage players to progress significantly further in the Tutorial puzzles was not supported, the narrative did demonstrably increase players' commitment to the experience in terms of time spent with the tutorial (H2). Possibly, the narrative did not significantly affect level progression because of the difficulty of some of the Tutorial puzzles—a known issue in *Foldit* [16, 37]. At a certain level of difficulty, no matter how engaging the story, some players simply get stuck.

In approaching our narrative design, we shared the assumption of other CSG developers that science fiction is particularly well suited to the goals of citizen science. Science fiction inherently allows for the emplotment of present-day scientific knowledge and research practices while simultaneously extrapolating their future implications. The genre also characteristically situates scientific and technological innovations in larger social contexts and dramatic plots that promote critical deliberation. Our survey results indicated that players of CSGs consume a lot of science fiction in different media formats, and they are strongly predisposed to favor science fiction as a narrative framing for a CSG. But most of our survey respondents also indicated a very strong predilection for fantasy in addition to science fiction. In general, it would seem that gamers who are interested in CSGs—and therefore presumably interested in science as such—predominantly prefer speculative fictions and other fantastical genres in the romance tradition more than genres that are based in the aesthetics of realism. This correlation poses some intriguing considerations about how players make distinctions between what counts as reliable scientific knowledge and what counts as make-believe, and how different fictional genres might productively help players to think about such distinctions and their implications when playing a CSG.

5.1 Limitations and Questions

This study faced a variety of limitations that raise further research questions. Because *Foldit* is an online game with a large, complicated codebase, the data had considerable noise. Some of this noise came from technical issues in the logging process or bugs in the user experience. Some noise came from the fact that, as noted above, *Foldit*—and especially Education mode [38]—is frequently assigned to biology students. Such students are often required to complete a certain number of Education levels or to reach a certain score in a level. They may also be better prepared to solve the more difficult protein puzzles. Their gameplay metrics therefore skew from those of average *Foldit* players. Another complicating factor was that, given the nature of the experiment, we did not publicly disclose the existence of a narrative in *Foldit*. New players were therefore not expecting to encounter a narrative, and some may have been confused by its presence in the game. Lastly, a few players noted in the surveys that, as experienced gamers, they had expectations for greater production values than what the *Foldit: First Contact* experiment could provide. This reflects what Miller and Cooper [36] found regarding the importance of game polish for CSGs. Further experiments that address these limitations may shed more light on the potential of game narratives to captivate citizen scientists.

Future work should also investigate player agency relative to CSG narratives. Do players react differently if they get a choice to opt in or opt out of a narrative experience? Some research has suggested that different kinds of players may have divergent responses to the presence of a narrative in a CSG [46, 48]. Other research has suggested that giving players a choice among narrative-based

rewards and nondiegetic rewards (points, badges, etc.) can improve engagement and the quality of contributions in a serious game [53]. Our experimental data indicated that while most players did engage with the story of *Foldit: First Contact* (e.g., "overall the whole idea was amazing"), a number of players apparently did not like it at all, quitting the game after reading only a small portion of the story. Giving players a choice to play *Foldit* either with or without a narrative campaign would potentially appeal to different kinds of players and enhance their experience with the game.

Relatedly, how would a dynamic narrative that reacts to a player's choices or performance affect the experience? Naul and Liu [43] describe four features of effective narratives for serious games with a purpose beyond entertainment. First, the narrative should be distributed, told in more than one way and with more than one media form, in order to reduce cognitive load. Second, the fantasy should be endogenous, intrinsically integrating the story and mechanics through a cohesive experience: a ludonarrative harmony (cf. [2, 18]). Third, the narrative should include empathetic characters: relatable, likable virtual agents. Finally, the storytelling should be adaptive and responsive, giving the player meaningful choices with meaningful outcomes. Our redesign of *Foldit* attempted to present story elements through different media forms, introduce colorful characters, and rhetorically reframe the protein puzzles of the Tutorial levels as components of a distributed narrative architecture, aiming for ludonarrative harmony. However, our experiment intentionally made no changes to the actual gameplay mechanics of *Foldit* or the contents of the puzzles, in order to isolate the effects of the narrative in comparison to the standard version of the game. Although the narration of *Foldit: First Contact* pretends that solving the protein puzzles has an effect on plot outcomes, completing the puzzles merely allows the player to progress through the storyline; the narrative does not actually adapt or respond to the player's actions. Given the results of this study, designing more elaborate, bespoke game experiments that allow for precise testing of different narrative features—including distributed narration, endogenous fantasy, empathetic characters, and adaptive and responsive storytelling—would be a good next step for understanding the functionalities of narrative.

Moreover, what happens when a narrative is employed at different stages of the citizen science experience? In this experiment, we wrapped a narrative around *Foldit*'s Tutorial mode. What effect would this narrative have on engagement if we instead targeted Foldit's Education mode or the Science puzzles—i.e., the core scientific gameplay loop? Some narrativized CSGs have introduced stories only paratextually, outside of the gameplay experience (e.g. *Eyewire*'s "Heroes of Neuroscience" story). Some, like *Foldit: First Contact*, have added stories to the in-game training modules but have left the core scientific research loops untouched (e.g. *Phylo*'s "Story Mode"). Some have inserted scientific mini-games into immersive storyworlds without organically linking their scientific contents to the narrative (e.g. the Borderlands Science arcade in *Borderlands 3*). Yet others have attempted to align their scientific contents with the narrative contents of the game (e.g. Project Discovery in *EVE Online*). Further research should examine the specific effects of these different ways of wrapping CSGs in story.

Finally, relative efficacies of different genres of fiction adapted for citizen science projects need to be studied. Although it is clear that citizen scientists enjoy a variety of popular narrative genres, and especially speculative and fantastical fictions, whether some genres are inherently better suited for particular citizen science projects should be tested in regard to their differential effects on participant engagement, learning, quality of scientific contributions, degree of ethical reflectiveness, and other factors.

5.2 Recommendations for CSG Narratives

Given our results, what can CSGs achieve by including a narrative? Most prominently, we have shown that a narrative can add depth of time commitment with neutral to positive effects on progression in an expertise-centric CSG. Other CSG projects with more emphasis on casual gameplay mechanics have similarly observed that narratives can attract players, and the embedding of real science in fictional storyworlds may account for the popularity of some of these games [10, 48, 54, 56, 62]. Moreover, a narrative can also afford other spin-off effects, such as enhancing understanding of the scientific topic, increasing curiosity, encouraging critical thinking, provoking reflection, and cultivating a sense of ethical responsibility [34, 35, 64].

We found that most players who seek out CSGs such as *Foldit* have a robust interest in science fiction and other genres of speculative and fantastical fiction. Situating a CSG narrative in the zone of science fiction is therefore likely to appeal to such players. However, the bar is high. Because so many players reported that they predominantly consume science fiction for recreational entertainment, they also may expect greater sophistication and self-awareness in the use of genre conventions and tropes in CSGs. They also may have higher standards in regard to literary and artistic quality, based on their familiarity with a wide range of science fiction media. CSG narratives drawn from other genres of fiction would also likely appeal to particular groups of players, though further research is needed on the capacities of different fictional modes for conveying the contents and contexts of citizen science.

For purposes of engaging players with a narrativized CSG, it also seems advisable to foreground the story and its function in the game. In this experiment, we did not advertise the existence of the *Foldit: First Contact* story at all. Some of our survey respondents noted that they were pleasantly surprised to discover a fictional narrative in an expertise-centric game like *Foldit* (e.g., "It was very original and funny, it was what i expected last from foldit"). The majority of players in our experimental group who began in Education mode also migrated toward the narrative after they discovered its existence. We infer from these results that highlighting the presence of a narrative in advance—whether on the game's website, in promotional materials, or through the design of in-game starting menus—not only would likely help to attract new players but also would mitigate any initial confusion some players might otherwise experience when presented with a fictional story as the entryway for a citizen science project.

However, our data also indicated that some players enjoyed the *Foldit: First Contact* narrative more than others. For purposes of engaging a diverse audience of citizen scientists and gamers, designers of CSGs may wish to give players some structural options for learning and interacting with the scientific contents of the game, for example, offering a choice whether to activate a narrative

campaign mode or instead to opt out (cf. [46, 53]). Doing so would accommodate players who enjoy stories as immersive experiences as well as players who prefer to skip the story and get directly into the scientific puzzles of the game.

In regard to game design and metrics of engagement, is it more important for players to progress or to be immersed? In either case, game behavior metrics are simply proxies for the values that CSG developers actually care about: do players understand the game and its science, can they grapple with the scientific challenges, and do they think about the broader implications of science in society? Ultimately, this may be the most salient reason for including narratives in CSGs: the potential for well-crafted stories to represent, recode, and reinforce these values of citizen science, above and beyond the immediate tasks and playable mechanics of the game.

6 CONCLUSION

Our findings suggest that wrapping a citizen science game in a fictional narrative can significantly increase player engagement, including greater involvement with core scientific tasks. However, most of the heightened engagement we observed can be attributed to players spending more time with the narrative itself. We conclude that stories can be compelling resources for citizen science projects but only if their particular qualities as stories are taken seriously. Stories should not be considered simply as lures, gimmicks, or clickbait entertainment (i.e., "Come for the story, stay for the science!"). Players come to citizen science games already with extensive experiences in the media ecologies and genre landscapes of popular culture, and they have a correspondingly sophisticated horizon of expectations (cf. [23]). Narratives that persuasively engage players and encourage them to stick around can enrich the citizen science experience by addressing issues that may not be self-evident in the core scientific tasks of the game, such as the social and ethical dimensions of research.

Using the tools of fiction—including mimesis, metaphor, symbolism, cognitive estrangement, and imaginative speculation—game narratives can situate participatory research, data gathering, and data analysis in larger contexts of meaning, enabling players to think about the stakes of their participation and to consider what their participation affords [34]. In this way, game narratives can contribute to the cultivation of thoughtful expertise and self-reflection among players, beyond the temporary amusements of gamification and the fun of solving puzzles. Wrapped in story, games can help players become rapt in the values of citizen science.

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