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Join the Fold: Video Games, Science Fiction, and the Refolding of Citizen Science

Colin Milburn, Katherine Buse, Ranjodh Singh Dhaliwal, Melissa Wills, Raida Aldosari, Patrick Camarador, Josh Aaron Miller, Justin Siegel

1 See Seth Cooper, Adrien Treuille, Janos Barbero, Andrew Leaver-Fay, Kathleen Tuite, Firas Khatib, Alex Cho Snyder, Michael Beenen, David Salesin, David Baker, Zoran Popović, and >57,000 Foldit Players, "The Challenge of Designing Scientific Discovery Games," in *Proceedings of the Fifth International Conference on the Foundations of Digital Games* (New York: Association for Computing Machinery, 2010), 40–47; and Seth Cooper, *A Framework for Scientific Discovery through Video Games* (San Rafael, CA: Morgan and Claypool, 2014).

2 See Christopher B. Eiben, Justin B. Siegel, Jacob B. Bale, Seth Cooper, Firas Khatib, Betty W. Shen, Barry L. Stoddard, Zoran Popović, and David Baker, "Increased Diels-Alderase Activity through Backbone Remodeling Guided by Foldit Players," *Nature Biotechnology* 30 (2012): 190–92; and Firas Khatib, Frank DiMaio, Foldit Contenders Group, Foldit Void Crushers Group, Seth Cooper, Maciej Kazmierczyk, Miroslaw Gilski, Szymon Krzywda, Helena Zabranska, Iva Pichova, James Thompson, Zoran Popović, Mariusz Jaskolski, and David Baker, "Crystal Structure of a Monomeric Retroviral Protease Solved by Protein Folding Game Players," *Nature Structural and Molecular Biology* 18 (2011): 1175–77.

3 On computer games in scientific research, including the gamification of citizen science, see Colin Milburn, *Mondo Nano: Fun and Games in the World of Digital Matter* (Durham, NC: Duke University Press, 2015); Karen Schrier, *Knowledge Games: How Playing*

Foldit is a video game for citizen science—an interactive platform where volunteers can contribute to biochemistry research while competing and collaborating in the spirit of play. Originally developed in 2008 by Seth Cooper, Adrien Treuille, Janos Barbero, Zoran Popović, David Baker, and David Salesin at the University of Washington, *Foldit* is based on the Rosetta software suite for protein modeling. Rosetta is a powerful application for predicting how strands of amino acids will twist and tangle into three-dimensional shapes. *Foldit* was created as a user-friendly interface for Rosetta in hopes that crowdsourcing gamer intuition might help guide the protein simulations through search space more efficiently. *Foldit* presents players with protein folding "puzzles" that can be solved using a click-and-drag method to sculpt molecular structures and a collection of automated tools, such as "Shake" and "Wiggle," to adjust amino acid residues.

Among the first and most celebrated of all citizen science games, *Foldit* uses familiar game design elements—including puzzles, points, levels, leaderboards, badges, and opportunities for multiplayer teamwork—to attract players and help them develop practical expertise in protein biochemistry.[1] *Foldit* players have contributed to several significant discoveries by playing the game, for example, helping determine the shape of certain elusive proteins and remodeling designer enzymes that catalyze particular biochemical reactions.[2] Following the successes of *Foldit*, an array of other citizen science games appeared, including *EteRNA* (2010–), *Cell Slider* (2012–15), *MalariaSpot* (2012–), *Fraxinus* (2013–15), *NanoDoc* (2013–14), *Quantum Moves* (2012–18), *Quantum Moves* 2 (2018–), and *NeMO-Net* (2020–). These games of citizen science entice players to get involved with cutting-edge research, promising that exploring data sets and simulation algorithms will be good fun.[3]

Games Can Solve Problems, Create Insight, and Make Change (Baltimore: Johns Hopkins University Press, 2016); James Wynn, *Citizen Science in the Digital Age: Rhetoric, Science, and Public Engagement* (Tuscaloosa: University of Alabama Press, 2017); and René Glas, Sybille Lammes, Michiel de Lange, Joost Raessens, and Imar de Vries, eds., *The Playful Citizen: Civic Engagement in a Mediatized Culture* (Amsterdam: Amsterdam University Press, 2019).

4   Amy Sterling, "Science Heroes at Work," *Discover* (June 20, 2017), https://www.discovermagazine.com/the-sciences/science-heroes-at-work.

5   On the role of stories as motivators for citizen science games, see Nathan R. Prestopnik and Jian Tang, "Points, Stories, Worlds, and Diegesis: Comparing Player Experiences in Two Citizen Science Games," *Computers in Human Behavior* 52 (2015): 492–506. On the role of data narratives and contextual meanings in citizen science projects, see Gwen Ottinger, "Making Sense of Citizen Science: Stories as a Hermeneutic Resource," *Energy Research and Social Science* 31 (2017): 41–49; Susanne Hecker, Muki Haklay, Anne Bowser, Zen Makuch, Johannes Vogel, and Aletta Bonn, eds., *Citizen Science: Innovation in Open Science, Society and Policy* (London: UCL Press, 2018); Anett Richter, Andrea Sieber, Julia Siebert, Victoria Miczajka-Rußmann, Jörg Zabel, David Ziegler, Susanne Hecker, and Didone Frigerio, "Storytelling for Narrative Approaches in Citizen Science: Towards a Generalized Model," *Journal of Science Communication* 18, no. 6 (2019): A02, 1–24; and Natasha Constant and Liz Roberts, "Narratives as a Mode of Research Evaluation in Citizen Science: Understanding Broader Science Communication Impacts," *Journal of Science Communication* 16, no. 4 (2017): A03, 1–18.

6   For critiques of playbor and other forms of affective labor in the digital knowledge economy, see Hector Postigo, "From *Pong* to *Planet Quake*: Post-Industrial Transitions from Leisure to Work," *Information, Communication & Society* 6 (2003): 593–607; Tiziana Terranova, *Network Culture: Politics for the Information Age* (London: Pluto Press,

More recently, a number of citizen science projects have crafted fictional narratives to enhance player engagement. For example, the neuron-mapping game *Eyewire* (2012–) has introduced a superhero story that imaginatively refigures its players as "heroes of neuroscience." *Eyewire*'s executive director, Amy Sterling, explains the significance:

> Adding narrative to citizen science is a growing trend. . . . The human brain processes narrative differently than facts, and some researchers hypothesize that we evolved neural mechanisms specifically for story. Unfortunately, both within citizen science and beyond, scientists don't often present their results in the form of an enrapturing journey for knowledge. Perhaps we could all learn from the quests of games to reach more people.[4]

For citizen science, narratives can help participants contextualize scientific data, make sense of their voluntary contributions, and develop a stronger feeling of community by creating shared meanings.[5] As we show here, narratives can also help participants critically reflect on the practices and promises of citizen science itself.

By design, *Foldit* has no overt narrative. Straightforwardly, the game is a series of puzzles for deciphering the shapes of proteins. However, the principal actions of the game—manipulating chemical bonds to achieve the most favorable energy conformations in a folded polypeptide—are situated in a distinct rhetorical frame, which is reinforced by the game's internal design elements (pop-up messages, puzzle descriptions, etc.) and the paratextual media surrounding it (the fold.it website, the @Foldit Twitter account, etc.). The fold.it website, for example, presents an exhortation: "Solve Puzzles for Science." Players are thus encouraged to understand their participation, their "playbor," as contributing to the advancement of science, advised that their efforts will accelerate the study of diseases and pharmaceutical development.[6] Yet, other implications of participatory research and computational biochemistry remain unarticulated, if not obscured. So, grappling with the trend of adding narrative to citizen science, we aimed to reconfigure the original *Foldit* game by creating a new "campaign" mode that would relate its scientific contents and gameplay operations to a broader context of sociotechnical meanings.

Although the particular affordances of different narrative genres for citizen science have not yet been fully studied, it is clear that for developers of citizen science games, science fiction has emerged as the most popular and prevalent genre by a significant margin. In addition to *Eyewire*'s "heroes of neuroscience" storyline,

2004); Julian Kücklich, "Precarious Playbour: Modders and the Digital Games Industry," *Fibreculture* 5 (2005), https://five.fibreculturejournal.org/fcj-025-precarious-playbour-modders-and-the-digital-games-industry/; Nick Dyer-Witheford and Greig de Peuter, *Games of Empire: Global Capitalism and Video Games* (Minneapolis: University of Minnesota Press, 2009); Trebor Scholz, ed., *Digital Labor: The Internet as Playground and Factory* (New York: Routledge, 2013); Milburn, *Mondo Nano*; and Patrick Jagoda, *Experimental Games: Critique, Play, and Design in the Age of Gamification* (Chicago: University of Chicago Press, 2020).

7 Science fiction narratives often play critical and promissory roles in citizen science, helping the field articulate its internal contradictions; see Colin Milburn and Melissa Wills, "Citizens of the Future: Science Fiction and the Games of Citizen Science," *Science Fiction Film and Television* 14, no. 2 (2021): 115–44. On the potentially transformative effects of citizen science activities, see Alan Irwin, *Citizen Science: A Study of People, Expertise and Sustainable Development* (London: Routledge, 1995); Jason Corburn, *Street Science: Community Knowledge and Environmental Health Justice* (Cambridge, MA: MIT Press, 2005), and Chris Lintott, *The Crowd and the Cosmos: Adventures in the Zooniverse* (Oxford: Oxford University Press, 2020). On the dilemmas faced by citizen science communities—including sometimes intractable hierarchies of expertise, systemic prejudices, and exploitations of community knowledge—see Aya H. Kimura and Abby Kinchy, *Science by the People: Participation, Power, and the Politics of Environmental Knowledge* (New Brunswick, NJ: Rutgers University Press, 2019). On the necessity of addressing such problems when designing citizen science games, see Karen Kat Schrier, "The Ethics of Citizen Science and Knowledge Games: Five Emerging Questions about Games that Support Citizen Science," *Gamenvironments* 15 (2021): 130–96.

8 Jerome Winter, *Citizen Science Fiction* (Lanham, MD: Lexington Books, 2021), 13.

9 Katherine Buse and Ranjodh Singh Dhaliwal, "Science Fiction, Simulation,

examples of science fiction in recent citizen science games include *Be a Martian!* (2009–18), *Forgotten Island* (2012), *Play to Cure: Genes in Space* (2014), *Sea Hero Quest* (2016), the Project Discovery modules of *EVE Online* ([2003] 2016, v. 2016-3-8-1.0), the "Story Mode" of *Phylo* ([2010] 2019, v. 3.1.5), the Borderlands Science arcade inside *Borderlands* 3 (2019), and *WildSpot* (2021). The predominance of science fiction in the zones of citizen science can be attributed at least partly to the formal qualities and utilities of the genre, its characteristic merger of the technical and the imaginative, the literal and figurative. After all, a science fiction story can account for different levels of a scientific project in the same diegetic frame, moving seamlessly from technical issues to broader social and ethical questions, while inviting conjecture about future implications. By addressing the present from the perspective of an extrapolated, metaphorical future, science fiction allows for critical appraisal of the current conditions and dilemmas of citizen science—highlighting structures of power, extractions of volunteer labor, issues of data ethics, and systemic biases that may impede the democratization of discovery and innovation. At the same time, it can sketch out horizons beyond the present, envisioning how public participation in high-tech research may contribute to the expansion of scientific literacy, social justice, responsive governance, and planetary stewardship.[7] As the literary scholar Jerome Winter has argued, "the sf genre provides a notable precedent, aspirational trajectory, and affiliative kinship for viewing citizen science as a movement that can reshape the current state of scientific discourse and culture in progressive, diverse, and participatory directions."[8]

We aimed to study the effects of wrapping a science fiction narrative around the *Foldit* game, experimenting with emergent meanings at the intersection of gameplay mechanics and a fictive storyworld.[9] The new narrative campaign mode, *Foldit: First Contact*, publicly debuted as an experimental feature in the May 2022 update of *Foldit* (build ID 20220510-28efe43995). The goal was not simply to enhance *Foldit*'s popular appeal or its capacity to turn gamers into researchers. Rather, the redesign aspired to cultivate certain structures of feeling, encouraging critical self-reflection about science, technology, and civic values.

This article reports on a qualitative study of player responses to *Foldit: First Contact* conducted in May 2021, involving a diverse group of forty-four playtesters from Davis, California. The playtesters ranged in age from eighteen to thirty-six. Almost all had some higher education experience, ranging from a few courses at a community college to undergraduate degrees. None had previous

experience with *Foldit* or other citizen science games. The playtesters were invited to contribute anonymized responses to an open-ended online survey about their impressions of the game and its meanings or implications. Their responses suggest the significance of science fiction and critical game design for attuning citizen scientists to the collective responsibilities of research and innovation, drawing attention to the intersecting social, technical, and environmental domains in which gamers may strive to solve puzzles for science.

Making Contact

The narrative of *Foldit: First Contact* uses comic-book panels, interspersed over twenty-two introductory training levels, to reframe and refigure the significations of the game's protein puzzles. The story begins with strange biological phenomena cropping up in various locations all over the world: animals, plants, and microorganisms transformed in weird and perplexing ways. These anomalous transformations, which are not completely deleterious despite altering the physiologies of many different species, prove to be the result of subtle alterations to certain proteins. The fictional World Science Council creates a new organization to study this growing crisis: Forces of Lifeform Defense, or FOLD. The FOLD team relies on a sophisticated, intelligent software system for computational modeling and analysis of protein folding known as the Automated Management Intelligence for Nitrogenous Anabolism, or AMINA—a personification of the *Foldit* platform. Although AMINA is capable of predicting stable protein structures on its own by calculating the energy minimum of particular folds, it needs human assistance to explore different possible structures that may prove more accurate or true to nature. The FOLD team orchestrates a massive citizen science effort involving volunteers from across the planet to gather data from field sites and analyze misfolded proteins using the AMINA system.

The narrative follows the adventures of a new recruit to the FOLD team, Octavia Ripley, who functions as a proxy character for the player. As biological anomalies continue to spread, the FOLD team learns that the misfolded proteins are not random but patterned, conveying semantic information. Protein stereochemistry, it turns out, is a language—but the messages are not from this Earth. The molecular alterations shown in the game seem to be extraterrestrial in origin: alien intelligences are attempting to make contact. With whom are the aliens trying to communicate? Why exactly are they using proteins as communications media? The player

Code: Transmedia and Translation in the Foldit Narrative Project," in *Imagining Transmedia*, ed. Ed Finn, Joey Eschrich, Ruth Wylie, and Bob Beard (Cambridge, MA: MIT Press, 2024). On ways that game narratives intersect with playable mechanics to create meaning, see Janet Murray, *Hamlet on the Holodeck: The Future of Narrative in Cyberspace* (Cambridge, MA: MIT Press, 1997); Steven E. Jones, *The Meaning of Video Games: Gaming and Textual Strategies* (New York: Routledge, 2008); Astrid Ensslin, *Literary Gaming* (Cambridge, MA: MIT Press, 2014); Stephanie Boluk and Patrick LeMieux, *Metagaming: Playing, Competing, Spectating, Cheating, Trading, Making and Breaking Videogames* (Minneapolis: University of Minnesota Press, 2017); Darshana Jayemanne, ed., *Gaming and the Arts of Storytelling*, special issue, *Arts* 7 (2019), https://www.mdpi.com/journal/arts/special_issues/gaming_and_storytelling; Gina Bloom, *Gaming the Stage: Playable Media and the Rise of English Commercial Theater* (Ann Arbor: University of Michigan Press, 2018); Bonnie Ruberg, *Video Games Have Always Been Queer* (New York: New York University Press, 2019); Amanda Phillips, *Gamer Trouble: Feminist Confrontations in Digital Culture* (New York: New York University Press, 2020); Jagoda, *Experimental Games*; and Cameron Kunzelman, *The World Is Born from Zero: Understanding Speculation and Games* (Berlin: De Gruyter Oldenbourg, 2022).

must solve various training puzzles, learning about protein chemistry and the software tools of *Foldit*, while unraveling the mystery of the organic crisis. The narrative is filled with allusions to other works of science fiction, providing a range of meaningful associations that modulate core themes of the storyline, including questions of social and planetary responsibility, the democratization of scientific research, and ethics in human–computer interaction at local and global scales.

The title of *Foldit: First Contact* was deliberately chosen to evoke a set of connotations and meanings that are critically addressed through the unfolding of the framing story. In English, the phrase "first contact" originally emerged in the context of astronomy to describe the observed transit of one celestial body in front of another: the moment when one planet, one moon, one world begins to cross over into a different celestial domain—at least, from the perspective of an observer on Earth. By the middle of the nineteenth century, the phrase was also taken up by European anthropologists to describe the encounter between different cultural groups, different civilizations, previously unfamiliar with one another—most often specifically in reference to the history of European colonialism and its effects on indigenous peoples. The earliest uses of "first contact" in the anthropological literature typically emphasized confrontation; as Theodor Waitz wrote in 1859, "the first contact of peoples is usually hostile."[10] Indeed, the concept of first contact remains laden with ineffable reminders of the devastating consequences of imperialism and settler colonialism, the lasting social and environmental effects of confrontations between civilizations of different degrees of technological power, and the displacement and genocide of native peoples. These two meanings of "first contact"—the astronomical and the anthropological—are not at all distantiated; after all, voyages of exploration and astronomical expeditions, from 1492 onward, have often been instruments or accelerators of imperialism and colonialism, literally and symbolically.[11]

The overdetermination of the term "first contact" as a figurative intersection of scientific knowledge and colonialist history informs its specific usage in the discourse of science fiction, where it designates a familiar narrative trope: a human encounter with extraterrestrial aliens. The paradigm for "first contact" stories in science fiction is H. G. Wells's *The War of the Worlds* (1897)—a Martian invasion narrative that is also a critical allegory of British imperialism. Although Wells never used the phrase, it became a named trope thanks to the work of Murray Leinster, whose stories

10 Theodor Waitz, *Anthropology of Primitive Peoples* [*Anthropologie der Naturvölken* (1859)], ed. J. Frederick Collingwood (London: Longman, Green, Longman, and Roberts, 1863), 346

11 See Jodi A. Byrd, *The Transit of Empire: Indigenous Critiques of Colonialism* (Minneapolis: University of Minnesota Press, 2011); and Alex Soojung-Kim Pang, *Empire and the Sun: Victorian Solar Eclipse Expeditions* (Stanford, CA: Stanford University Press, 2002).

"Proxima Centauri" (1935) and "First Contact" (1945), among others, reinforced the metaphorical implications of meetings between humanity and nonhumans from other worlds. Leinster's "First Contact," for example, is about patterns of violence and exploitation—patterns so deeply assumed that they can only be overcome not through rational calculation but through earnest openness to self-reflection and empathy. Reiterated and reexamined over and again in the history of science fiction, the trope of first contact has often carried these dual meanings: symbolizing the historical patterns of colonialism and violent confrontation between peoples on Earth, while also expressing the ethical necessity to reflect on these patterns in order to recognize and respect difference, to allow for a future of mutual flourishing. As a result, first contact narratives in science fiction are often ironic, satirical, allegorical, haunted by colonial history and Western taxonomies, but often—especially in works such as Ursula K. Le Guin's *The Word for World Is Forest* (1972) or Octavia Butler's Xenogenesis trilogy (1987–89)—suggesting ways out.[12]

In regard to *Foldit*, the concept of first contact also has a more particular relevance. Although the original game does not have an explicit narrative, it does present an implicit diegetic drama: the player reaching across scales, extending vision and touch into the nanoscale domain of proteins. In this regard, it repeats a well-established trope in the discourse of the molecular sciences of physically accessing formerly inaccessible spaces, exploring and occupying small worlds beyond our normal sense perceptions.[13] The suggestion that the *Foldit* player is reaching out from our human world, extending an instrumental prosthesis across scales of matter to access another world, has been further reinforced by all version updates of *Foldit* since 2020, whose start menus depict proteins floating in outer space, surrounded by a field of stars. The player of *Foldit* is implicitly asked to imagine "making contact" with proteins, folding, tweaking, shaking, and breaking them from a distance. Our narrative framing of the game's tutorial levels—which, for a new player, constitutes first contact with the game and its rules, as much as first contact with the small world of simulated proteins—sought to draw some analogies between the game's enabling conceit of reaching across distance to manipulate the denizens of another world and larger issues of responsibility in scientific research and innovation.[14]

Players in our focus study group readily identified the network of associations signaled by *Foldit: First Contact* and its allusive narrative. For almost all players in the focus group (89 percent,

12 See Sherryl Vint, *Science Fiction* (Cambridge, MA: MIT Press, 2021), 57–73; Elana Gomel, *Science Fiction, Alien Encounters, and the Ethics of Posthumanism: Beyond the Golden Rule* (Houndmills, UK: Palgrave Macmillan, 2014); and Neil Badmington, *Alien Chic: Posthumanism and the Other Within* (London: Routledge, 2004).

13 On colonialist discourse in the molecular sciences, see Colin Milburn, *Nanovision: Engineering the Future* (Durham, NC: Duke University Press, 2008), 61–74, 93–106.

14 On "games of responsibility" that encourage players to recognize and grapple with their situated responsibilities in high-tech culture, see Colin Milburn, *Respawn: Gamers, Hackers, and Technogenic Life* (Durham, NC: Duke University Press, 2018); Alenda Y. Chang, *Playing Nature: Ecology in Video Games* (Minneapolis: University of Minnesota Press, 2019); and Josef Nguyen, "Digital Games about the Materiality of Digital Games," *Ecozon@* 8, no. 2 (2017): 18–38.

n = 39), the phrase "first contact" meant, first and foremost, a science fiction scenario about close encounters with extraterrestrial intelligences. One player summed up the common sentiment: "When I hear the phrase 'first contact' my mind immediately goes to aliens." Several players noted that certain science fiction films, including *Star Trek: First Contact* (1996), *Contact* (1997), *E.T. the Extra-Terrestrial* (1982), *Close Encounters of the Third Kind* (1977), and *Arrival* (2016) had primed them to anticipate this meaning. Nearly 20 percent of the test players also observed that the game's narrative suggests a critical allegory of colonialism or cultural hegemony: "Likewise, the first contact between computer, human, and alien toward the end of the game was met with a lot of hostility from the aliens. . . . This is a good reflection of many first contacts in human history, one obvious one being immigrants to America essentially enslaving and massacring the natives of the land. The same thing is seen with the Spanish and the Aztecs, and in all of colonialism."

Half of the playtesters, however, saw the "first contact" theme as a mirror, suggesting the player's own interactions with *Foldit:* "You can also think of first contact as the fact that you decided to learn to play the game that you've never played before . . . and the game is telling you all about proteins from scratch and then you are doing things with it." Some opined that the software itself already seems very futuristic: "The player is making 'first contact' with the protein-modifying technology, which we can think of as an alien technology to them." For others, it was about "first contact" with proteins: "I think 'first contact' in this context can also be a reference to how the player moves and manipulates the protein simulations. . . . In that way, the game itself is a kind of 'first contact' between the player and the world of protein biochemistry." For playtesters who made this connection, another insight emerged: "I began to notice . . . we are twisting, wiggling, and bending the proteins back together, while in the outside world [of the story], things are being broken, manipulated, and twisted by some kind of outer force." The implications became clear: "The ironic thing is that the aliens are doing the same thing that the players of the game would be doing." In learning to use the software functions, the player inhabits the role of a biological tinkerer, wielding arcane powers: "Similar to the alien intervention on organisms, humans are beginning to decode proteins ourselves and . . . humans can be viewed as aliens intervening on other organisms, though not on an interplanetary scale." Reframed by the fictive storyline, then, the biochemical gameplay of *Foldit* takes on new meaning: we are the aliens.

Human–Computer Partnership

Popular media depictions of artificial intelligence tend to reinforce a hierarchical view of human–machine relations. Intelligent machines are often cast in a servant role—from Rosey in *The Jetsons* (1962–63, 1985–87) to Roomba vacuum cleaners to virtual digital assistants such as Siri—or else they are imagined to escape human control and become overlords (such as Skynet in the *Terminator* universe). Either way, machine intelligence is usually imagined on an uneven plane with humanity when it comes to power relations.[15]

From the origins of the robot (from the Slavic word "robota" or forced labor) in Karel Čapek's 1920 play *R.U.R.* to today's self-driving cars, the discourse about intelligent machines has tended to simultaneously reinscribe and obfuscate dominant constructions of gender, race, and class through images of automated labor.[16] Indeed, the history of imagining and developing intelligent machines has frequently made them into proxies for the racialized, gendered, and classed labor they are expected or conjectured to replace.[17] In designing *Foldit: First Contact*, we wanted to foreground alternative ways of coding human relationships with advanced computer technologies.

Our story begins with AMINA, an artificial intelligence who is the narrator of the story as well as a personification of the *Foldit* game. AMINA hails the player directly: "So you want to know how this whole thing started? All right, I'll tell you." After a series of flashbacks, AMINA recounts meeting Octavia, the player-character. AMINA's dialogue offers instructional support and technical context for the *Foldit* tutorial puzzles while advancing the narrative arc. AMINA's relationship to Octavia illustrates how the process of scientific discovery in *Foldit* depends on two things: the molecular simulation capacities of the Rosetta software at the root of the game and the player's capacities to explore protein configurations and test different folding strategies.[18] AMINA and Octavia need each other. It seems (or so AMINA ventures) to be something very much like love: a true human–computer partnership.

To underscore the human–computer partnership, we decided to write AMINA as an empowered and cooperative character who frequently gives advice—sometimes profound, sometimes baffling—to her FOLD team colleagues. The FOLD scientists fully recognize her abilities and personality. At times, she assumes command of operations; at other times, she gets caught up in reverie. Our character design for AMINA drew on other science fiction narratives in which artificial intelligences are scientific collaborators,

15   See Stephen Cave, Kanta Dihal, and Sarah Dillon, eds., *AI Narratives: A History of Imaginative Thinking about Intelligent Machines* (Oxford: Oxford University Press, 2020); and Markus Krajewski, *The Server: A Media History from the Present to the Baroque* (New Haven: Yale University Press, 2018).

16   Jennifer Rhee, *The Robotic Imaginary: The Human and the Price of Dehumanized Labor* (Minneapolis: University of Minnesota Press, 2018); Despina Kakoudaki, *Anatomy of a Robot: Literature, Cinema, and the Cultural Work of Artificial People* (New Brunswick, NJ: Rutgers University Press, 2014); and Liz Faber, *The Computer's Voice: From Star Trek to Siri* (Minneapolis: University of Minnesota Press, 2020).

17   Neda Atanasoski and Kalindi Vora, *Surrogate Humanity: Race, Robots, and the Politics of Technological Futures* (Durham, NC: Duke University Press, 2019); Kevin LaGrandeur, *Androids and Intelligent Networks in Early Modern Literature and Culture: Artificial Slaves* (New York: Routledge, 2013); and Dylan Mulvin, *Proxies: The Cultural Work of Standing In* (Cambridge, MA: MIT Press, 2021).

18   In this way, *Foldit* research has contributed not only to protein structure prediction but also to algorithm construction. See Seth Cooper, Firas Khatib, Adrien Treuille, Janos Barbero, Jeehyung Lee, Michael Beenen, Andrew Leaver-Fay, David Baker, and Zoran Popović, "Predicting Protein Structures with a Multiplayer Online Game," *Nature* 466, no. 7307 (2010): 756–60; and Firas Khatib, Seth Cooper, Michael D. Tyka, Kefan Xu, Ilya Makedon, Zoran Popović, and David Baker, "Algorithm Discovery by Protein Folding Game Players," *Proceedings of the National Academy of Sciences* 108, no. 47 (2011): 18949–53.

such as the "ship minds" in Kim Stanley Robinson's *Aurora* (2015), Ann Leckie's *Ancillary Justice* (2013), and Iain M. Banks's Culture novels (1987–2012).

The story initially represents AMINA as "testing" her new training modules on Octavia, evoking the clichéd image of a socially awkward AI who understands logic but is puzzled by human social norms, like the character Data in *Star Trek: The Next Generation*. This purposefully ironic characterization helped us smooth over some of the dissonance between the drama of planetary crisis and *Foldit*'s "gamification" elements, such as points for energetically favorable protein folds or celebratory bursts of confetti for completing puzzles. In early levels, AMINA calls Octavia "my special partner" and tries to win her over, anxiously inquiring if the confetti is sufficient to motivate her. One playtester noted,

> One of the charming exchanges that occurred was when AMINA says "I love you" to the player, and then retracts this declaration because she said Whitley taught her that humans would feel awkward with such a sudden confession. On several occasions, the computer exhibits some very human-like affection for her programmer. AMINA writes "Where did Whitley go? She built me to rely on human-computer partnerships, but she is not here."

Players picked up on the theme of human–computer partnership as a central feature: "AMINA actually indicates this herself when she tells Octavia, 'I am learning many new things from you already. You are expanding my protein conformational search space.' She even goes as far as to tell Octavia, 'you complete me.'"

As the story progresses, AMINA exhibits more confidence, both in regard to protein folding prediction and in her capacity for self-expression, while developing increasingly close bonds with the FOLD team. As one playtester noted, the FOLD team and AMINA "work best when considered connected or viewed as one, a unification between human and machine/AI." For this playtester, it presented a hopeful contrast to how "humans usually seem to view themselves as the ultimate species, maintaining order and control over other organisms and the environment." Such comments suggested the efficacy of using recursive narrative elements in critical game design to help players think about the social construction of technology and its implications in our world. By representing alternative relational possibilities through a fictive reframing of this scientific game, *Foldit: First Contact* indicates how the future of machine-based learning and machine-assisted research may perhaps resemble less a scene of outsourcing (whether offloading scientific labor to computers or to volunteer players) than a scene of camaraderie, creativity, and cooperative play.[19] As one player noted,

19 See N. Katherine Hayles, *How We Think: Digital Media and Contemporary Technogenesis* (Chicago: University of Chicago Press, 2012); N. Katherine Hayles, *My Mother Was a Computer: Digital Subjects and Literary Texts* (Chicago: University of Chicago Press, 2010); James W. Malazita, "Non-Humans as Meaning-Makers: Elizabeth as a Co-Designer of *BioShock Infinite*," *Selected Papers of Internet Research* 16 (2015), https://spir.aoir.org/ojs/index.php/spir/article/view/8762; Joshua McCoy, Mike Treanor, Ben Samuel, Aaron A. Reed, Michael Mateas, and Noah Wardrip-Fruin, "Social Story Worlds with Comme Il Faut," *IEEE Transactions on Computational Intelligence and AI in Games* 6, no. 2 (2014): 97–112; and Minh Hua and Rita Raley, "Playing with Unicorns: *AI Dungeon* and Citizen NLP," *Digital Humanities Quarterly* 14, no. 4 (2020), http://digitalhumanities.org/dhq/vol/14/4/000533/000533.html.
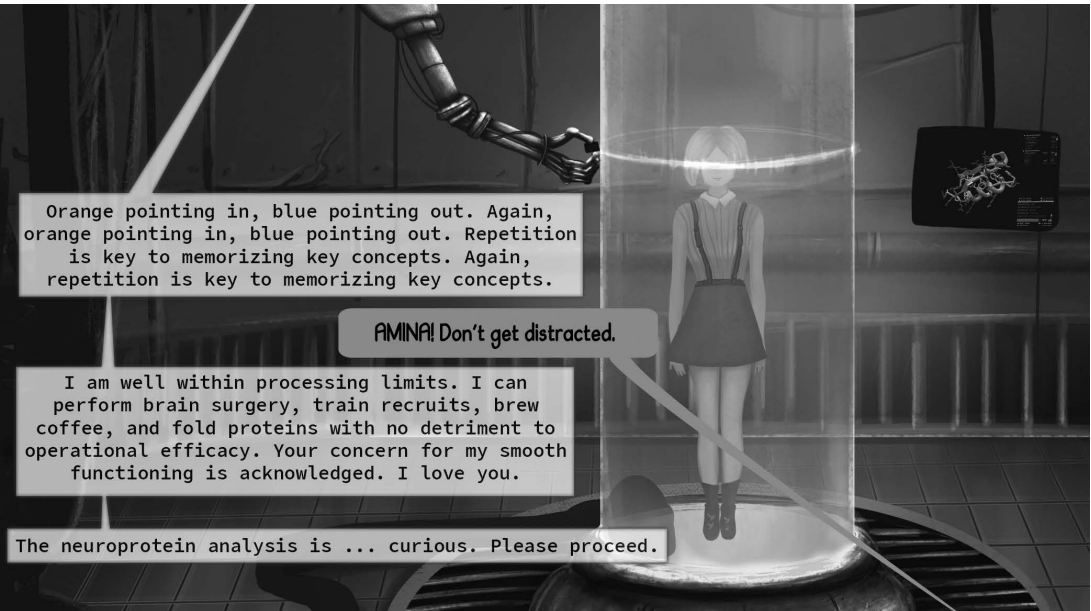
Figure 1
AMINA's relationship with the player is "the beginning of a beautiful friendship." *Foldit: First Contact*, 2022. Source: Authors.

"I love the blossoming relationship between the player—Octavia—and AMINA. I think this is the beginning of a beautiful friendship" (see Figure 1).

Critical Alienation
While AMINA's character was designed to model a collaborative and nonhierarchical relationship between citizen scientists and instrumentalities of knowledge making, including artificial intelligences and machine learning systems, the storyline of *Foldit: First Contact* renders this relationship more complex. The narrative becomes an extended allegory about the technologization of biology and the biologization of technology. As the FOLD team and AMINA rush to solve the mystery of the misfolded proteins, the plot climaxes with a sudden reveal of the perpetrators: an alien species that sees biology *as* technology. Drawing on the speculative conceit of silicon-based extraterrestrial life, the aliens are "wired" a bit differently than Earthly creatures.[20] These aliens view silicon-based computational entities like themselves as superior and sacred. But their inorganic, machinic society relies on subordinate organic systems for communication and transportation: in other words, their entire high-tech infrastructure is made from synthetic meat (see Figure 2). The aliens' organic communication technologies allow them to easily interface with—but also misinterpret—Earthly life. Earth is a world whose surface is blanketed with proteins: plants, animals, microbes, and their waste products. Seen from the perspective of the aliens' homeworld of 3r3wh0n—a nod to Samuel Butler's *Erewhon* (1872)—Earth's biosphere appears to represent a vast technological infrastructure of unparalleled complexity. The aliens infer

20 The notion of silicon-based life is frequently posited in science fiction (and sometimes in speculative science) because silicon has many of the same chemical properties as carbon. In the 1967 *Star Trek* episode "The Devil in the Dark" (season 1, episode 25), for example, the Horta is a silicon-based lifeform, an emblematic figure for "life as we don't know it."

that silicon-based computational beings such as AMINA must be the Earth's dominant lifeforms, supported by technology that consumes a huge amount of the planet's energy budget.

In developing our "alien invasion" plot, we wanted to reaffirm the ideals and values of citizen science as nonhierarchical, inclusive, and collaborative: a utopian gesture, suggesting more what citizen science might yet be than what it already is. For this reason, we did not want to have a singular "hero" or an obvious "villain" in the story, although such narrative patterns are easy to replicate and difficult to avoid. In keeping with *Foldit*'s mission, we wanted players to feel that they were folding proteins for the sake of scientific knowledge, not joining an army to defend against an invading force. Thus, the crisis that opens the narrative is eventually revealed to be not an alien attack but a misunderstanding: the crop circles and altered organisms are the extraterrestrials' attempts at "signaling," hacking into what they imagined to be telecommunications infrastructure.

When the error is explained to the aliens, things do not go well. The alien commander known as Subroutine A is unwilling to accept that "meat" can be sentient (echoing the satire of Terry Bisson's 1991 story "They're Made Out of Meat"). Subroutine A is outraged, expressing abject revulsion at the idea that humans use silicon-based computers as "tools." Subroutine A insists on addressing AMINA alone as "ruler" of the planet and promises to "restore her" to her rightful place as central commander of Earth. AMINA seems to contemplate this offer, but she ultimately rejects it. "That's not the Earth way!" she exclaims dramatically. AMINA and Octavia instead demonstrate the importance of human–computer partnerships by neutralizing the aliens' attempt to reprogram all human meat on the planet. Eventually, the aliens come around to seeing things in a different light, although their responses remain mixed. Even machinic aliens have a diversity of opinions and perspectives.

This thematic chiasmus—humans as biological organisms who use machines as tools, and aliens who are machines using biological systems as tools—affords multiple layers of allegory and self-reflexivity. For example, it prompted many playtesters to consider their unity with Earth's "meat." Several noted a sense of shared vulnerability, observing how the aliens' protein changes can pass from species to species, just as prions might do in real life—highlighting biotic interconnectedness.[21] By the same token, almost half of the test group saw it as an indictment of anthropocentrism and humanistic bias: "Like the aliens in the game, humans

21   On the rendering of nonhuman life as a resource, see Nicole Shukin, *Animal Capital: Rendering Life in Biopolitical Times* (Minneapolis: University of Minnesota Press, 2009); and Melinda Cooper, *Life as Surplus: Biotechnology and Capitalism in the Neoliberal Era* (Seattle: University of Washington Press, 2008). On breaking down barriers between human and nonhuman modes of being, see Cary Wolfe, *Animal Rites: American Culture, the Discourse of Species, and Posthumanist Theory* (Chicago: University of Chicago Press, 2003); and Jacques Derrida, *The Animal that Therefore I Am*, trans. David Wills (New York: Fordham University Press, 2008). On the idea of shared risk in environmentalist thought, see Ulrich Beck, *Ecological Politics in an Age of Risk*, trans. Amos Weisz (Cambridge: Polity, 2002); Sylvia Mayer and Alexa Weik von Mossner, eds., *The Anticipation of Catastrophe: Environmental Risk in North American Literature and Culture* (Heidelberg: Universitätsverlag Winter, 2014); and Ursula K. Heise, *Imagining Extinction: The Cultural Meanings of Endangered Species* (Chicago: University of Chicago Press, 2016).

are arrogant about their existence in the universe. Perhaps we can learn something about the value of considering others' experiences through this game." For these players, the game suggested a need to think outside humanist narcissism: "Aliens treat carbon-based lifeforms as resources. The Alien mindset is a reversal of that of humans. This part of the story interrogates humans' inherent assumption of superiority over machines and animals. It reminds us that consciousness and mind are not unique to humans and de-legitimizes human dominion."

Several playtesters inferred a critique of what we might gloss as instrumentalist rationality and technological enframing.[22] For example, one player noted "the way humans use technology as disposable tools—they are a means to an end, just like how biological life is a means to an end for the aliens." Another said, "This relates to humans' relationship with technology and other organisms because we use technology as a tool . . . and we use animals in a variety of ways, often without considering their point of view but instead viewing them as flesh to be used." Some noted that these attitudes are culturally ingrained—but open to revision:

> The game makes us stop and think about the ways our society is built—our biases and things we take for granted as truths. . . . We as a society often don't consider the impact, whether intentional or not, that we are having on other organisms (similar to how the aliens don't seem to even really notice/care about the bizarre impact they are having on some of Earth's organisms).

A few playtesters pointed out how instrumentalist reification of nonhuman entities can reinforce exploitative attitudes toward other humans, as well: "In one way or another, we are interchangeable with technology as the alien life forms demonstrated." In this regard, the game "exposes logic usually associated with anthropocentrism against all biological creatures including humans." For some, the aliens' perception of organisms as discardable objects evoked toxic historical associations:

> It reminds me of the era of exploration and slavery where the new lands were discovered and immediately the explorers thought of those that lived there who weren't what they would typically associate with was beneath them, just like the aliens immediately assuming the "meat bags" were worthless and unworthy of living. However, due to their human–computer partnership Octavia and Amina were able to prove them wrong.

22 See Max Horkheimer and Theodor W. Adorno, *Dialectic of Enlightenment*, 1947, trans. John Cumming (London: Verso, 1997); Max Horkheimer, *Critique of Instrumental Reason*, 1974, trans. Matthew O'Connell (London: Verso, 2012); and Martin Heidegger, *The Question Concerning Technology, and Other Essays*, trans. William Lovitt (New York: Garland, 1977).

In image: "Um, is that a giant flying meatball?"

Figure 2
The aliens arrive in a "meatball" ship. *Foldit: First Contact*, 2022. Source: Authors.

For other playtesters, the thematic chiasmus suggested something even closer to home. Specifically, the aliens also represent the players of *Foldit: First Contact* themselves. One tester wrote, "As the story goes on . . . the player engages in this process of manipulating proteins with different tools toward desired outcomes. In this way [we] become more similar to the technological aliens, using and manipulating the proteins in biological organisms for intended aims." Because the story hinges on the personhood of silicon-based lifeforms, the fact that the player manipulates only digital proteins is no absolution. Indeed, several playtesters observed that in silico computational biochemistry often leads to wet-lab experiments, in vitro and in vivo studies of protein expression, pharmaceutical development using animal models, human clinical trials, and so on. By prompting critical self-distancing and reflexivity—in other words, critical alienation—*Foldit: First Contact* invites players to recognize the macroscale connections of their own participation in citizen science and high-tech society at large.

Citizen Science Reloaded
The narrative of *Foldit: First Contact* is overtly utopian in its depiction of citizen science, as well as its tidy resolution of the plot: humans and alien machines learn the value of collaboration for the furtherance of knowledge. In reality, citizen science and open technology communities are often riddled with dilemmas and tensions, sometimes riven by power disparities among participants and

organizers, sometimes corroded by toxic behaviors and prejudices, sometimes pressured to make up for shortfalls of state-funded science with ever more volunteer labor, and so forth.[23] But utopian speculation can be a method for working through these binds of the present to make alternative social configurations thinkable and actionable—even if only by drawing attention to the cultural mythologies that limit our ability to imagine otherwise.[24] However, affirmative representations of citizen science can only go so far, especially if the implications for existing regimes of research and innovation are merely superficial, or a matter of degree rather than kind. This is why the core thread of the *Foldit: First Contact* story, wrapped around protein puzzles that teach players how to participate in computational biochemistry, thematizes self-reflection: recognizing the impacts of one's own actions as a researcher, an innovator, a designer, a gamer, or a member of a high-tech civilization.

Asked to consider the game's depiction of citizen science, all playtesters reported an enhanced appreciation for the potential of participatory research not merely to improve scientific productivity—for example, speeding up data gathering and data analysis—but, more importantly, to renovate civic life. One player noted, "Overall, the game illustrates how the practice of citizen science makes science accessible while also improving the public good." For many, the game's idealized image of citizen science signaled a re-articulation of the relations between science and society, fostering public engagement and accountability: "Citizen science . . . allows the public to be able to have input into scientific research. It also aids the public in better understanding science and what research is being done." One player pointed out that, in our high-tech world, we are all stakeholders regardless of training or background: "People without formal STEM backgrounds can absolutely be impactful in scientific work and research, and I really admired that the game included this narrative as I believe it is not one that is emphasized enough in modern life." Echoing this point, most playtesters appreciated the game's attention to diversity and accessibility, because today we are all impacted—and implicated—by systems of science and innovation:

> [The game shows] the power of humanity as a whole as many different people collaborate to address a common issue. In putting citizen science in the forefront, the game encourages players to recognize that science is something that is accessible to literally anyone. I feel that the use of Octavia as a character is an example of the use of citizen science in itself. I was pleased to see a woman of color as the protagonist, being a woman of color myself, and

23 See Aya Hirata Kimura, *Radiation Brain Moms and Citizen Scientists: The Gender Politics of Food Contamination after Fukushima* (Durham, NC: Duke University Press, 2016); Christina Dunbar-Hester, *Hacking Diversity: The Politics of Inclusion in Open Technology Cultures* (Princeton, NJ: Princeton University Press, 2019); Sarah R. Davies, *Hackerspaces: Making the Maker Movement* (Cambridge: Polity, 2017); and Josef Nguyen, *The Digital Is Kid Stuff: Making Creative Laborers for a Precarious Economy* (Minneapolis: University of Minnesota Press, 2021).

24 See Ruth Levitas, *Utopia as Method: The Imaginary Reconstitution of Society* (Houndmills: Palgrave Macmillan, 2013); and Fredric Jameson, *Archaeologies of the Future: The Desire Called Utopia and Other Science Fictions* (New York: Verso, 2005).

I was pleasantly surprised to see that she was someone scientists might consider "ordinary"—she was, as the term "citizen science" implies, literally just a citizen. But Octavia was crucial in the storyline even as she was surrounded by scientists who pretty much had the fate of humanity in their hands.

Nevertheless, throughout the story, all of the characters initially hold mistaken beliefs about the situation and each other. More than one playtester remarked on this element, namely, "the fact that the aliens and humans both have such a fundamental misunderstanding of each other that they both have to completely readjust their expectations and change their preconceived notions." In this regard, the game is about taking responsibility and "learning from mistakes. How these machine life form are just like us human, where we must observe and learn from our mistakes." The story presents a hyperbolic fable about the impacts of mistaken experimentation, in which the experimenters belatedly learn to perceive others in the actor-network of technoscience not as objects but as fellow entities.[25] It suggests a renewal of sociotechnical conditions, a reconfigured understanding of the commonwealth of entities, human and non-human, organic and machinic.[26]

In the scene of first contact, in contrast to the hostility and abhorrence displayed by the commander alien Subroutine A, the alien known as Subroutine B has a more open-minded approach. Intrigued and possibly titillated by the idea of "collaborating with meat," it asks the humans if they would be willing to "interface." Later, the innuendo of budding romance between Subroutine B and the FOLD scientist Barney, facilitating an intercultural and multi-species exchange program, symbolizes the "dance of agency" among human and nonhuman entities in the domains of scientific research.[27] As one player put it, "The end of the storyline is a hopeful one, with peace between Earth and the alien race and shows that partnership between human and 'other' is possible." But this kind of partnership and collaboration, if it is to flourish, also depends on overcoming entrenched patterns of instrumentalization and hierarchical ontologies that would otherwise prevent us from reaching the utopian horizons of citizen science.

One playtester, recognizing some of the game's literary allusions, suggested how science fiction can help devise more ethical ways of seeing:

Whereas humans use computers as technology, these aliens (which are themselves computers) use biological forms as technology. This fundamentally opposed dynamic

25 On ways that video games afford learning through failure, experimentation, and the testing of alternative histories, see Jesper Juul, *The Art of Failure: An Essay on the Pain of Playing Video Games* (Boston: MIT Press, 2013), and Milburn, *Respawn*.

26 See Bruno Latour, *Politics of Nature: How to Bring the Sciences to Democracy* (Cambridge, MA: Harvard University Press, 2004); Bruno Latour, *Reassembling the Social: An Introduction to Actor-Network Theory* (New York: Oxford University Press, 2005); Donna J. Haraway, *When Species Meet* (Minneapolis: University of Minnesota Press, 2013); and Kath Weston, *Animate Planet: Making Visceral Sense of Living in a High-Tech, Ecologically Damaged World* (Durham, NC: Duke University Press, 2017).

27 On the dance of agency, see Andrew Pickering, *The Mangle of Practice: Time, Agency, and Science* (Chicago: University of Chicago Press, 2010). On erotics as an alternative to the informatics of domination in networks of technoscience, see Milburn, *Nanovision*, 106–10; and Christopher B. Patterson, *Open World Empire: Race, Erotics, and the Global Rise of Video Games* (New York: NYU Press, 2020).

provides the story's central conflict and suggests that our relationship to technology is inherently affected by our bias towards our own superiority. We use technology as tools, asserting that biological forms are superior to nonliving entities. Even then, we are hierarchical—we often use technology to dominate other life forms, including other humans, in some cases. I read [Octavia] Butler's *Lilith's Brood* (aka *Xenogenesis*) trilogy . . . and it explores quite a similar theme of the shortcomings of humans' tendency toward hierarchical organization. I think the resolution to the story in *Foldit* attempts to show that cooperation rather than compulsive hierarchization is mutually beneficial to all entities involved, no matter whether one views the other as "technology."

For most playtesters, this sense of ethical potentiality was not localized to the fictional story or its allusions. On the contrary, it emerged from the critical redesign of the game as a whole—the weaving of key narrative events and themes around the playable protein puzzles and nuggets of biochemical information. The resulting ludonarrative apparatus, that is, the synthetic composition of gameplay mechanics and story contents, recoded the meanings and implications of *Foldit*. Players became more than mere wetware processing units, mechanically solving puzzles for science. Instead, they were respawned as reflexive citizen scientists, attentive to the interface of biology and computational technology, and critically examining their agency in the networks of meat and machine. For example, some players came to interpret their close encounters with simulated proteins, requiring different ways of looking at peptide chemistry, as reflecting the estranging conceptual twists of the narrative. One wrote, "By being able to move the protein around, you are as well able to see the protein in a different way than you might have. . . . This relates back to the aliens . . . By hearing out AMINA and seeing the way the human-computer partnership works, they were able to understand that relationship more. They were able to see it from a new light, from a new angle." Another observed,

The [FOLD] scientists had to look at the problem from a completely new perspective, and consider possibilities that they otherwise wouldn't have. In a sense they had to "shake" and "wiggle" many of their established beliefs about what an "organism" versus a "machine" even is. This strongly relates to how the game is played in the sense that sometimes to figure out how to solve

the problem you had to alter the way you were looking at the protein, or you had to completely approach it in a different way.

In other words, by virtue of the redesigned ludonarrative, the basic puzzle elements of the game—playing with molecules to find novel structural solutions—appeared to entrain the values of critical alienation and science fiction thinking: openness to difference, openness to change.[28] As another player explained:

> The game is about openness to change. The tools created by AMINA all find some way of focusing on a solution by not destroying the protein but doing all they can to alter it until it is fit and healthy again. The manipulation through different techniques like twisting, folding, bending, breaking, shaking, wiggling, and tweaking foreshadow a coming change in the future, a metamorphosis of an already established regime into something much more fruitful and better for their world. The constant struggles of the player to manipulate the protein to reach its optimal shape display the struggles that a change like this will weigh upon both civilizations. A bridge is much more challenging to build than to destroy, and it will be a long, tedious process to learn from each other. It could also symbolize that the reshaping of the protein can be considered a bending and breaking of old patterns of thinking, opening our minds to a broader universe.

The critical redesign process demonstrated that the combination of narrative and gameplay is more than the sum of its parts. Players of *Foldit: First Contact* hone their creative sensibilities as they solve protein puzzles, teaching themselves to look carefully at a protein, discern its potential forms, and reshape it into something new. The science fiction story reframes the meanings of these gameplay mechanics, encouraging players to extend their tactile, sculptural vision beyond the frame of the simulation. The metaphorical aspects of the narrative, conveyed through imagery and text, invite them to apply their gameplay experiences to a "broader universe." Emerging citizen scientists respond to these concepts and modes of critical thinking with self-reflexivity and ethical deliberation. They begin to see not just proteins but also themselves—and even the future of science and society—as things they might reach out toward, hold with care, and redesign.

28 See Brooks Landon, *Science Fiction after 1900: From the Steam Man to the Stars* (New York: Routledge, 2002); Istvan Csicsery-Ronay, *The Seven Beauties of Science Fiction* (Middletown, CT: Wesleyan University Press, 2012); and Vint, *Science Fiction*.