NanoAdventure: Development of a Text-Based Adventure Game in English, Spanish, and Chinese for Communicating about Nanotechnology and the Nanoscale

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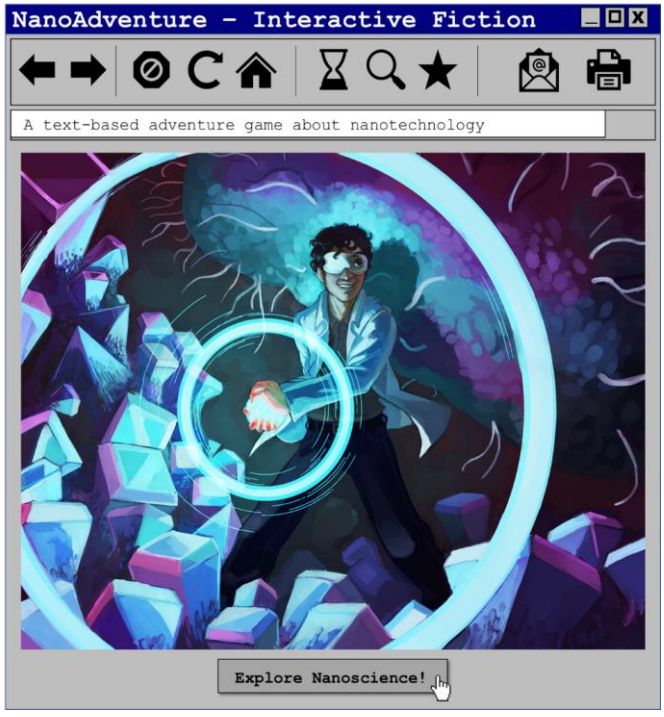

ABSTRACT

Video games and immersive, narrative experiences are often called upon to help students understand difficult scientific concepts, such as sense of scale. However, the development of educational video games requires expertise and, frequently, a sizable budget. Here, we report on the use of an interactive text-style video game, NanoAdventure, to communicate about sense of scale and nanotechnology to the public. NanoAdventure was developed on an open-source, free-to-use platform with simple coding and enhanced with free or low-cost assets. NanoAdventure was launched in three languages (English, Spanish, Chinese) and compared to textbook-style and blog-style control texts in a randomized study. Participants answered questions on their knowledge of nanotechnology and their attitudes towards nanotechnology before and after reading one randomly assigned text (textbook, blog, or NanoAdventure game). Our results demonstrate that interactive fiction is effective in communicating about sense of scale and nanotechnology as well as the relevance of nanotechnology to a general public. NanoAdventure was found to be the most 'fun' and easy to read of all text styles by participants in a randomized trial. Here, we make the case for interactive "Choose Your Own Adventure" style games as another effective tool among educational game models for chemistry and science communication.

INTRODUCTION

Scale is a common theme across most chemistry courses. However, scale, relative scale, and "scale literacy" are frequently a point of difficulty for novice learners.[1] Becoming comfortable with concepts in nanoscience and nanotechnology is one area in which the concept of scale, better known as "scale literacy", is particularly essential for students. One factor in developing expertise and sense of relative scale is the ability to visualize spatial scales.[1,2] Because of the immersive narrative that compels the reader-player to imagine the scale, such games are especially promising for educational purposes in this area.

Educational video games are not new to either the video game industry or the science, technology, engineering, or mathematics (STEM) community. Specifically, the chemistry and biochemistry communities have notably taken advantage of educational puzzle games such as FoldIt, an online puzzle game about protein folding, and EteRNA, an online game about RNA folding and confirmation.[3,4] These games are well known for recruiting players to act as citizen scientists and contribute answers to the respective fields by community puzzle solving at a rate faster than could be achieved by a single research team.[4,5] The chemical education community has developed several video games that can be played by students on a smartphone. These smartphone games both engage students and increase student comprehension of key

concepts.[6–8] Other chemical education video games and interactive modules that more closely resemble traditional desktop games, including those that use augmented reality technology, have been developed for education and instrument training.[9–12] While video games are more popular and easier to construct than ever before, the development of a video game – scaffolding, programming, and asset development or purchasing, to name a few factors – often involves the coordination of a large team with expertise.[13] This need for coordination, specialization, and the cost of development, means that game production is often inaccessible to educators looking to produce custom, tailored interactive materials for their courses.

Although the prospect of developing a video game can be daunting, there is one genre of video game that is especially accessible for educators and students. Text-based adventure games (also called 'interactive fiction' and 'gamebooks') are games that required only text. This genre of games is very similar to 'Choose Your Own Adventure' or 'Secret Path' gamebooks that were popular in the 1980s and 1990s. In interactive fiction, the reader/player assumes the role of the protagonist, and the text is often written in the second person (i.e. "You open the door"). Rather than providing a single narrative, interactive fiction provides the reader with the ability to make choices about the path of their story. Ultimately, the ending of the narrative is reached through a decision tree format with storylines and branches as complex as the author wishes. Interactive fiction/text is a popular genre of video games and includes titles such as *Zork!* (Infocom,1980) and *The Hitchhiker's Guide to the Galaxy* (Infocom,1984). This genre also includes visual novels, a form of mixed-media interactive fiction popularized in Japan in the 1990s, which drew inspiration from the murder-mystery interactive text game, *The Portopia Serial Murder Case* (Enix,1983). Interactive fiction games can be purely text-only or enhanced with sound effects, music, videos, and simple animations. Interactive fiction is also a genre that is particularly well suited to a single developer or author. For example, one particularly successful horror visual novel*, Doki Doki Literature Club* (Team Salvato, 2017), was written and coded solely by Dan Salvato using an open-source platform.[14] Open-source platforms are also accessible enough that interactive fiction games can be designed by students; Professor Adam Hammond of the University of Toronto assigns students the task of developing an interactive text-based game in his course 'Introduction to Digital Humanities: Literature in the Digital Age', using the open-source platform, Twine.[15] Interactive narratives have also been used by the U.S. Department of Health and Human Services and the Office of Research Integrity in their training module, *The Lab*,[16] which allows players to navigate a suspected case of scientific misconduct and understand the consequences of their choices during key points in the narrative. Due to the flexibility and accessibility of the genre, we propose that interactive fiction is a video game style

that is adaptable to the needs of chemical education and accessible to educators and students without requiring the expertise or expense of other genres of video games.

Interactive fiction is often primarily text and has much in common with traditional narratives and adventure literature. There are many examples of science educators leveraging the power of stories, including adapting Sherlock Holmes mysteries for chemistry education and using case studies from medical dramas to teach biochemistry.[17,18] Interactive fiction games combine the appealing nature of narrative with the sense of control a player has in the video game. Adventure games are also notable because they can include motivating factors, such as problem-solving, and their narrative motif of The Hero's Journey has been suggested to be a strong model for learning.[19] By embracing the format of text-based adventure games, the chemical education community can leverage the accessibility of development as well as the key benefits of narrative storytelling to create interactive educational modules for any number of chemistry topics. To explore the potential of interactive fiction, we have written a text-based adventure game focused on the exploration of the nanoscale world and various nanotechnologies.

Novice chemistry students may struggle with a sense of scale and understanding relative and absolute scales of sizes relevant to biochemistry, nano-chemistry/technology, and the development of an atomistic worldview.[1,2] Frequently, media seeks to express a sense of relative scale through the 'shrinking down' of a human protagonist or following an anthropomorphized creature character that exists at a non-visible scale. This motif is prevalent in science education media such as *The Magic School Bus* and *Osmosis Jones*, as well as in non-educational media, such as *Honey, I Shrunk the Kids*.[20–24] As a sense of scale is so key to chemical literacy and understanding of nanotechnology, yet still a key point of difficulty for students, we have developed a text-based adventure game, dubbed 'NanoAdventure', to explore the utility of interactive fiction for teaching learners about scale and nanotechnology. NanoAdventure is heavily inspired by a Sustainable Nano blog post titled "Zack's Nano Adventure."[25] To assess the efficacy of the text-based adventure in this study, we compared the interactive NanoAdventure with blog-style and textbook-style content in their effectiveness and audience enjoyment for explaining key concepts of scale and nanotechnology.

DESIGN AND RATIONALE

Because accessibility for the designer is a focus of this project, we used the open-source software Twine 2[26] to design the NanoAdventure game. Twine has been used to develop popular games, including *DepressionQuest* (Zoë Quinn, 2013) and *The Writer Will Do*

Something (Matthew S. Burns and Tom Bissel, 2015), and has a robust community of users who produce free resources and guides to using the platform.[27] Twine provides the game designer with a visual interface in which to write and connect text passages (**Figure 1**) and allows one to see the entire story flow at a glance. The designer can also enhance the game with pictures and sound. Twine has recently been used as a platform for remote Choose Your Own Adventure Labs in organic chemistry.[28] For NanoAdventure, it was important to include images in the game, including scanning electron microscopy (SEM) micrographs, to help reader-players visualize the setting of a nanoscale world. While micrographs are helpful for students learning to visualize the non-visible world, original art was also commissioned to depict a specific scene and emphasize the sense of scale. Additional visuals for NanoAdventure were provided by collaborators in the NSF Center for Sustainable Nanotechnology, obtained from repositories of images licensed under a Creative Commons license (e.g. Flickr), adapted from photos of our own lab spaces, drawn to resemble micrographs, and produced using Protein Data Bank Files rendered in Chimera (Resource for Biocomputing, Visualization, and Informatics (RBVI) at the University of California, San Francisco). Background music was included to set the tone of the game and to help indicate changes in location within the story. Total costs for additional assets (art commission, music files) were approximately $105 USD. All other additional assets were produced in-house or were free through Creative Commons licenses. Full artist credits are included on the Credits page of the game.

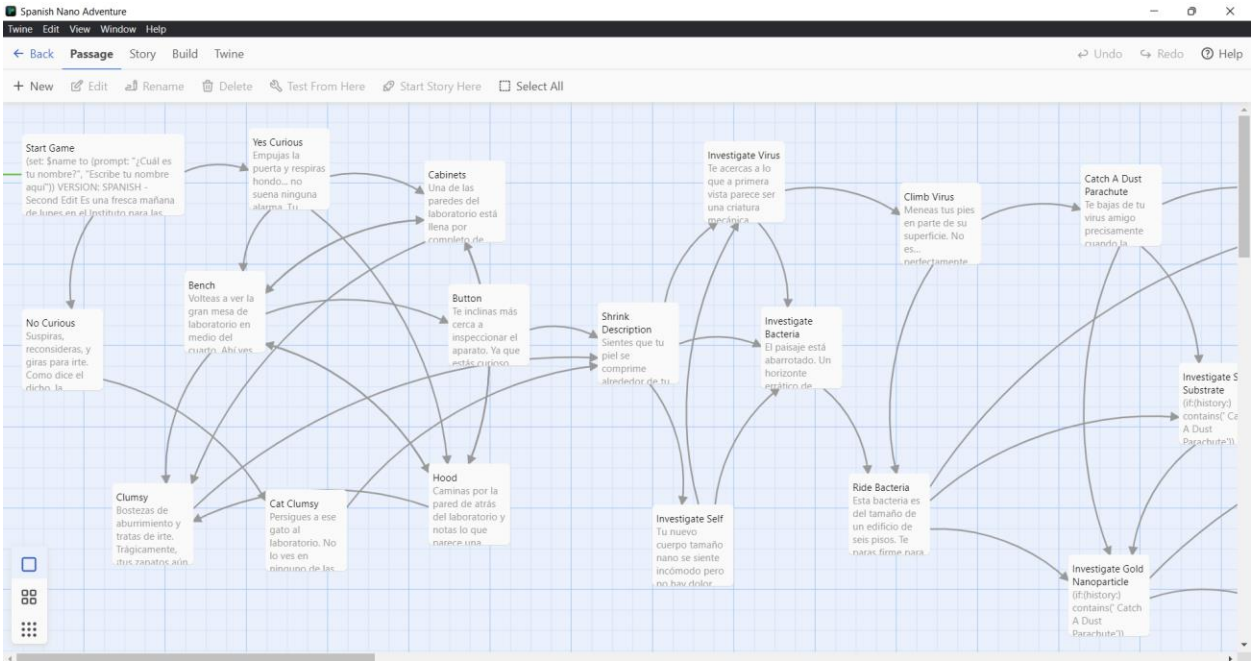

Figure 1. Natalie V. Hudson-Smith's view of the NanoAdventure development window displaying a Spanish language version of NanoAdventure as it is viewable to the designer in Twine.

Although win vs. lose conclusion scenarios are common in interactive fiction and certainly could be well-used in interactive fiction for chemical education, all NanoAdventure story branches converge to a single "win" conclusion. A win-only game design was chosen to allow for the comparison between different styles of texts and because participants would only be able to play through the game once for the study. Additionally, the reader-player was not expected to come into the game with any knowledge of nanotechnology, and NanoAdventure is designed to be a fun introduction to new concepts as opposed to a summative evaluation. The reader-player can reach the win/end condition of NanoAdventure by one of three paths that are influenced by their choices.

"Puzzling" is a feature of many interactive fiction games and frequently uses an input parser software element to evaluate user input (e.g. *The Portopia Serial Murder Case*, *Space Quest* Series, Sierra On-Line). Puzzles often require the player to input text that is either valid (leads to the next section or performs an action) or invalid (is not accounted for in the program or cannot be parsed). While this feature can be used for educational games, it can also be frustrating for players with insufficient knowledge. As NanoAdventure is designed to introduce a wide audience to a sense of scale and examples of nanotechnology, NanoAdventure was programmed without any puzzling aspects. Instead, players move based only on their choices and do not need produce a specific "correct" input.

The text of NanoAdventure and comparison texts were translated into Spanish and Chinese by co-authors fluent in speaking and writing each language in order to reach a wider audience of participants and to recognize and counter the dominance of English language resources in science communication.[29] The content was translated directly, with no special attention to making the story culturally relevant for Spanish- or Chinese-language participants; perhaps this was one reason for the low response rate for the non-English-language participants. This will be considered in future studies using this text-based adventure approach.

NANOADVENTURE NARRATIVE

In the original blog post that inspired the NanoAdventure,[25] the author, Zachary Jones, describes how the world would look to a person with a height of 100 nm and uses descriptive language to bring the nanoscale world to life by invoking the motif of the "Incredible Shrinking

Man" and the "Shrink Ray".[23,24] In the NanoAdventure game, the player plays as themselves embarking on a field trip to a scientific lab that houses both realistic and fantastical research projects. Either purposefully or by accident depending on player choices, the reader-player shrinks themselves down to a 100 nm height. An exploration of the seemingly endless landscape follows as the reader-player attempts to return to a normal size. These adventures lead the player through explorations of at a least two nanotechnologies (surface-enhanced Raman spectroscopy (SERS), carbon dots, or lithium-ion battery cathode nanomaterials) and interactions with at least one microbe (a bacterium or a virus) until they find another nanoscale person, the scientist Zack. Screenshots from the English version of NanoAdventure, depicting the start of the game, an early passage, and the reader-player encounter with Zack are shown in **Figure 2**.

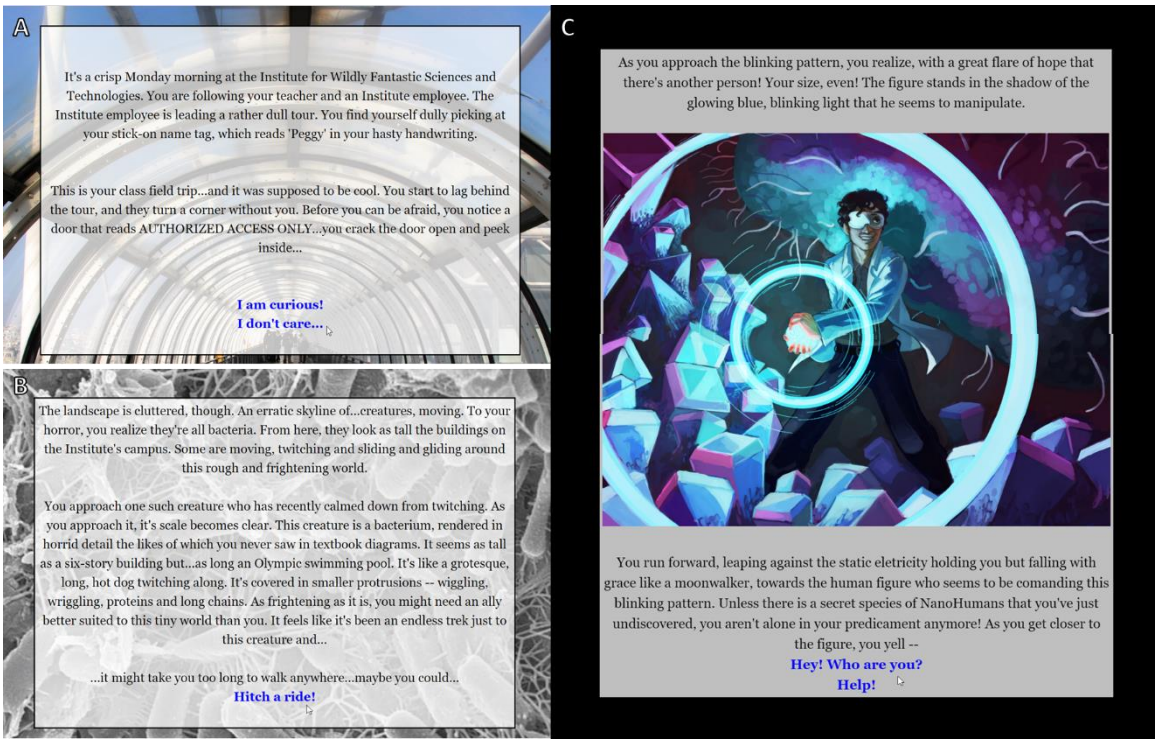

Figure 2. Scenes from the NanoAdventure text-based adventure game: A) the first passage players encounter, B) a passage describing the nanoscale world to the now 100-nm-tall player character, and C) the player encounter with Zack, holding a blinking carbon dot. Art by Kyle Galbraith.

Using their past experiences, the reader-player and Zack devise a plan to rescue themselves using nanotechnology. In the game, "if/else" statements are used to provide a narrative consistency, and the reader-player's previous choices influence their dialogue with Zack. A brief

outline of the paths available in NanoAdventure is shown in **Figure 3**. Although NanoAdventure features several nanotechnologies and applications, including mesoporous silica nanoparticles, gold nanoparticles, and protein-nanoparticle complexes, these are not explained in technical detail.

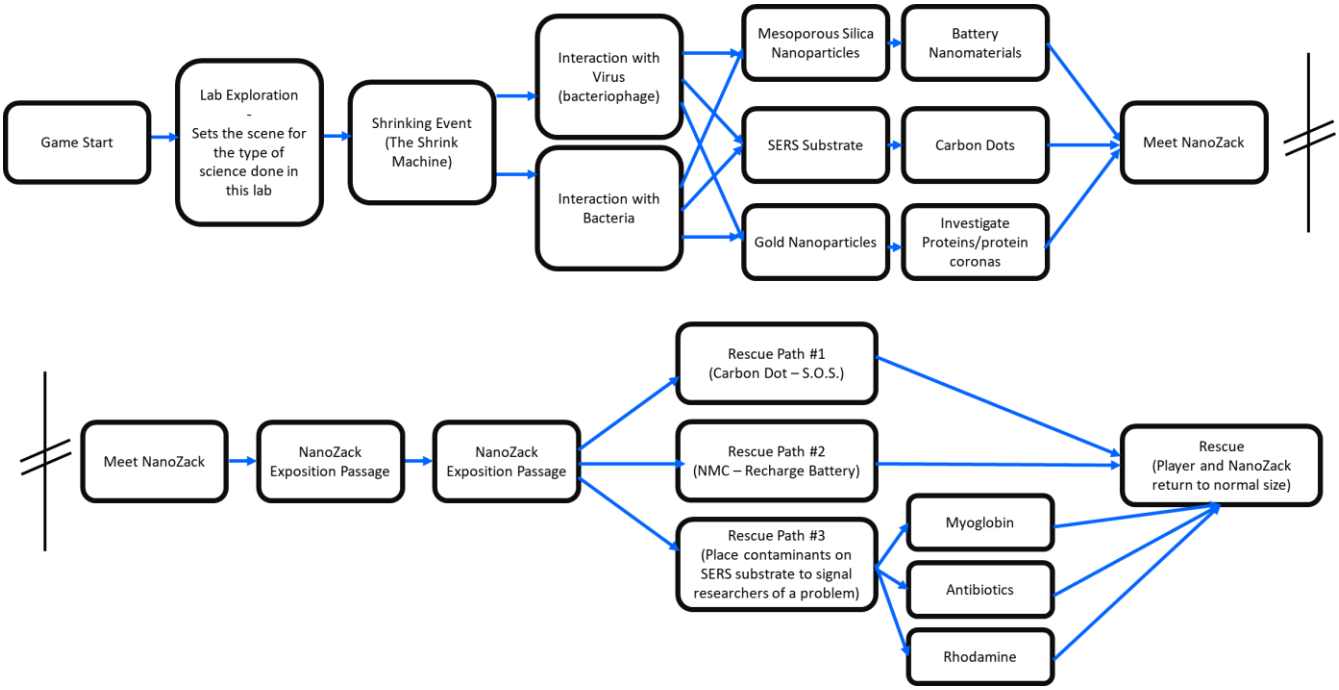

Figure 3. A brief outline of the narrative paths available in NanoAdventure.

EXPERIMENTAL DESIGN AND IMPLEMENTATION

To understand how interactive fiction was perceived and compared with traditional educational texts, we tested NanoAdventure against “textbook style” and “blog style” control texts with a similar wordcount. (An average play of NanoAdventure is approximately 3000 words.) The first control text was written by authors familiar with NanoAdventure to cover the same themes and topics but in the style of textbooks. A second control text was written by the same authors but in the style of the Sustainable Nano blog, which is written primarily by graduate students working to develop science communication skills.[30] All texts were translated by one or more of the authors from English to Spanish and Chinese. Participants were able to select their language preference prior to the start of the study and passed a short consent quiz to indicate that they had read and understood the terms of participation in their chosen language. The consent quiz was implemented to meet the conditions for approval by the Institutional Review Board and demonstrate that the participant was fluent in the selected language.

Limited demographic information (age, gender, level of education) was collected that may represent a limitation to the study. Participants answered 15 Likert-scale questions regarding knowledge and attitudes about nanotechnology. Of these questions, ten were asked both before and after the participants read a randomly assigned style of text (Textbook, Blog, or Game). Five of these questions covered factual statements about nanotechnology and five cover attitudes about nanotechnology. These questions have been used previously in assessing the role of text writing style in science communications about nanotechnology.[31–33] Participants answered these 10 “knowledge” and “attitude” questions prior to reading and immediately after reading their randomly assigned texts. Finally, after reading the text, participants answered five Likert-style questions about their attitude regarding the text they had just read. An outline of the evaluation flow is shown in **Figure 4**. The demographic questions, “knowledge” and “attitude” items, and “text attitude” items are shown in **Table 1**. The study was hosted through Qualtrics. For recruitment, the study link was posted to the SustainableNano blog and associated social media accounts and made available on survey swapping services. Study procedures were approved as IRB Exempt under ID # STUDY00010026.

For data analysis, responses that were incomplete or did not pass the comprehension and consent quiz at the beginning were discarded. Pre- and post- reading results for each group were compared within groups by a paired T-test. Results between groups for “text attitude” items were compared with an ordinary one-way ANOVA with post-test Tukey’s multiple comparisons. Responses to the questions were translated into numerical values such that Definitely True = 5, Likely True = 4, etc.

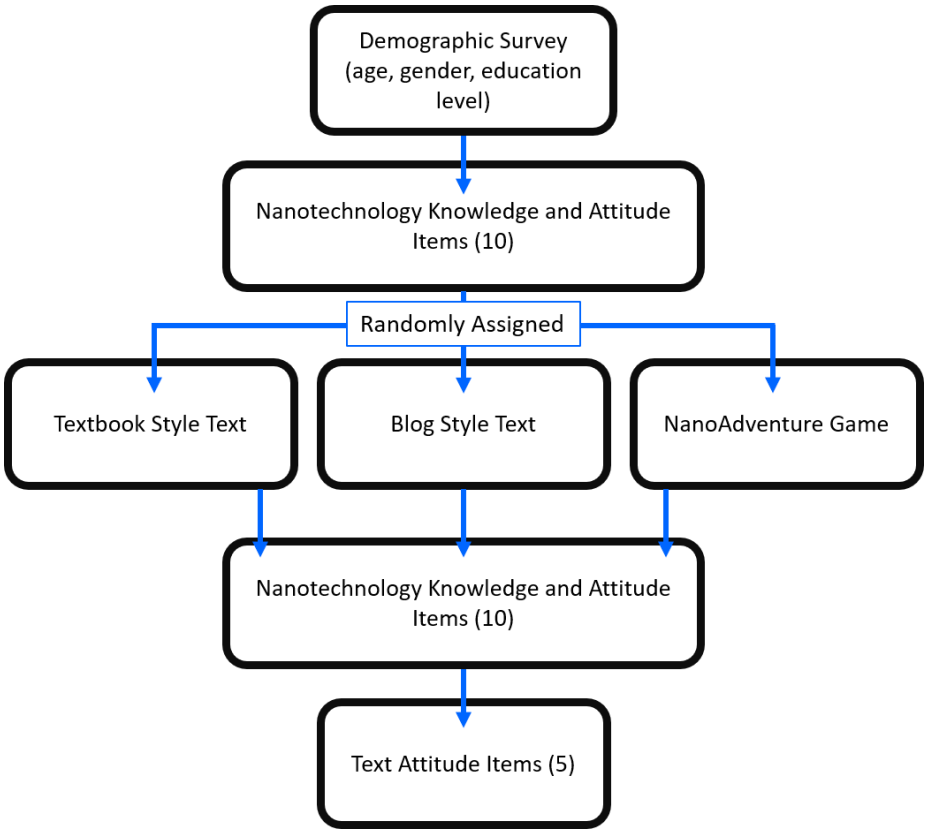

Figure 4. The survey flow for evaluation of NanoAdventure and comparison texts.

Table 1. Demographic, knowledge, and attitude survey items for the evaluation of NanoAdventure.

Demographic Items	Answer Format
What is your age?	Drop down selection – Arabic numerals
What is your gender?	Short answer form
Please indicate your highest level of formal education	Drop down selection: No schooling completed Nursery school to 8th grade Some high school, no diploma High school graduate, diploma or the equivalent (e.g. GED) Some college credit, no degree Trade/technical/vocational training Associate degree Bachelor's degree Master's degree

	Professional degree Doctorate degree
Nanotechnology Knowledge and Attitude Items (Pre-Reading Number, Post-Reading Number)	**Answer Format**
a. Nanotechnology involves materials that are not visible to the naked eye. (Q4.1, Q23)	Definitely True / Likely True / Likely False / Definitely False / I Don't Know
b. A nanometer is one billionth of a meter. (Q4.2, Q24)	Definitely True / Likely True / Likely False / Definitely False / I Don't Know
c. Nano- is smaller than bacteria. (Q4.3, Q25)	Definitely True / Likely True / Likely False / Definitely False / I Don't Know
d. Nanotechnology allows scientists to arrange molecules in ways that do not normally occur in nature. (Q4.4, Q26)	Definitely True / Likely True / Likely False / Definitely False / I Don't Know
e. Nanotechnology and nanomaterials have diverse applications. (Q4.5, Q27)	Definitely True / Likely True / Likely False / Definitely False / I Don't Know
f. Nanoscience and nanotechnology are useful for researchers and scientists. (Q5.1, Q28)	Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
g. Nanoscience and nanotechnology are useful for me. (Q5.2, Q29)	Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
h. Nanoscience and nanotechnology have an impact on my life or will in the future. (Q5.3, Q30)	Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
i. Nanoscience and nanotechnology are interesting. (Q5.4, Q31)	Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
j. Nanoscience and nanotechnology are dangerous. (Q5.5, Q32)	Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
Text Attitude Items	**Answer Format**

a. I have gained knowledge through the text that I can apply to scientific thinking and problem solving.	Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
b. I enjoyed the text.	Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
c. The text made me curious about nanoscience.	Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
d. The text was fun to read.	Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
e. The text was challenging to read.	Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree

RESULTS

After removing incomplete responses, 204 responses were retained (N= 204). Of these, 178 responses were from the English version, 24 from the Chinese version, and two from the Spanish version. Based on the small sample size for the Spanish and Chinese versions, no language-specific conclusions were drawn; instead, respondents were grouped only by the relevant type of reading (textbook, blog, game). Text style was assigned randomly, with 66 participants assigned to Textbook Style, 68 assigned with Blog Style, and 69 assigned to Game (NanoAdventure) Style. Languages were aggregated together into their corresponding Style group.

The average age of participants was 28 years old (28.2 ± 10.6) (**Figure 5**). The full range of reported ages was 14 to 79 years old. Participants were asked to self-report their gender identity in a short answer form, and gender demographics of participants are shown in **Figure 6**. Finally, participants were asked to indicate their highest level of education as shown in **Figure 7**. As mentioned previously, we collected limited demographic information that may represent a limitation to our study for foreign countries have different attitude towards technology that may represent bias in the study. [34] As well, approximately 13% of adults in the United States population have an advanced (Master's or Doctorate) degree[35] while in our participant pool, this proportion was approximately 42%. This could be because participants were recruited from existing Sustainable Nano readers, social media followers, and fellow

researchers on survey exchange services, biasing the study recruitment toward those interested in science and research.

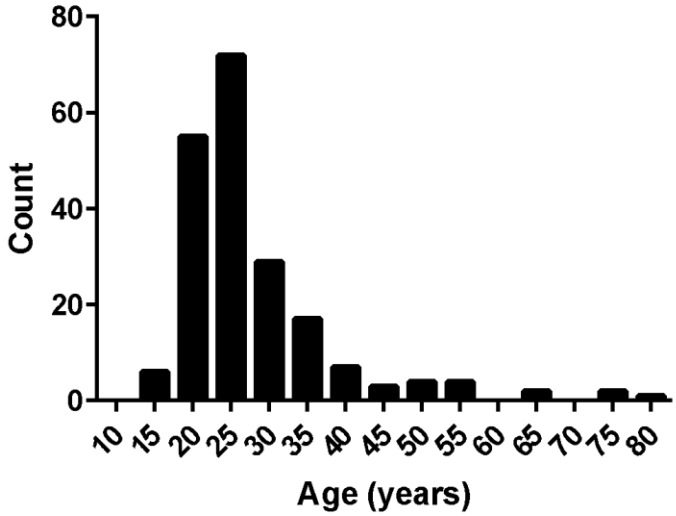

Figure 5. Histogram of participant ages.

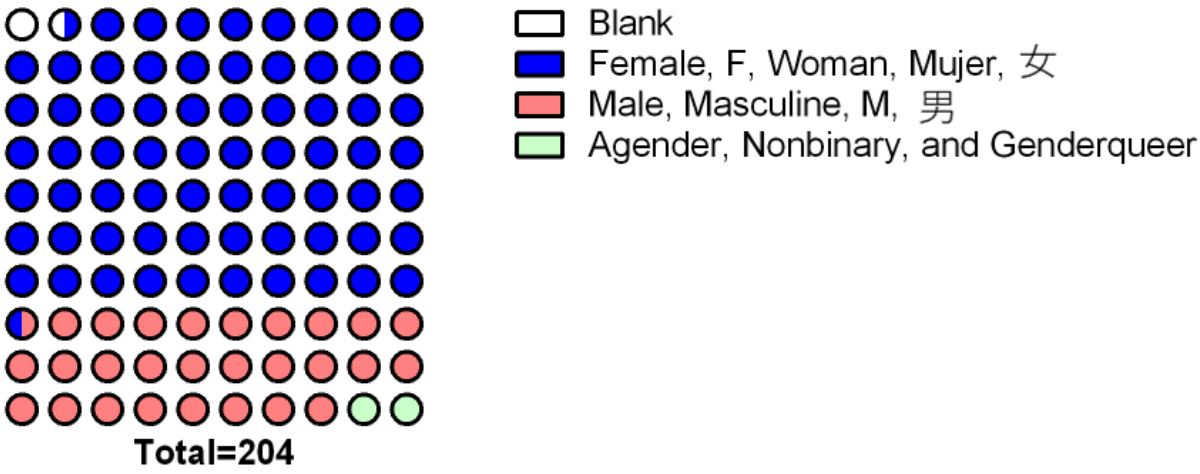

Figure 6. Participants' self-reported gender identities, grouped together as indicated in the legend.

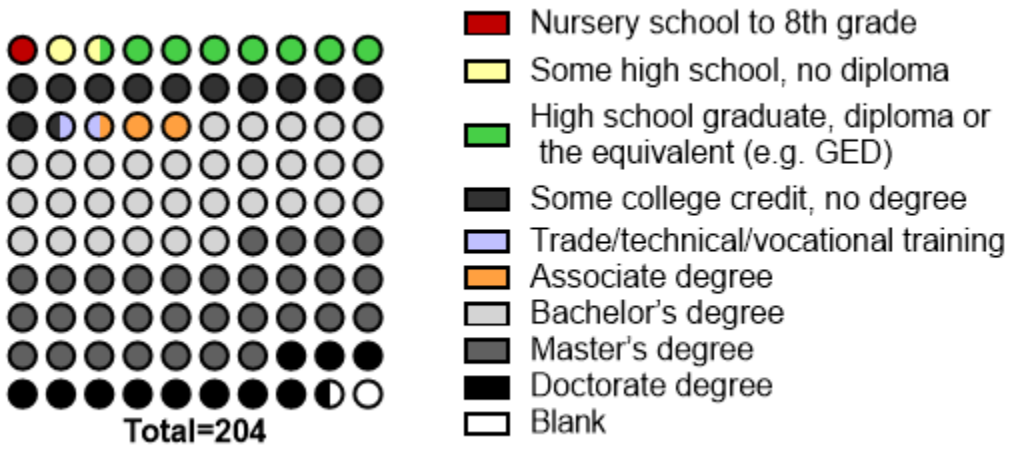

Figure 7. Participants indicated highest level of formal education.

KNOWLEDGE OF NANOTECHNOLOGY

Participants were asked five questions about their knowledge of nanotechnology (**Table 1**, Items a-e). For all knowledge questions and groups, there was either no significant change or a statistically significant increase in knowledge. In the Textbook group, four of five statements showed a statistically significant increase in knowledge. In the Blog group, all statements showed a statistically significant increase in knowledge. In the NanoAdventure Game group, three of five statements show a statistically significant increase in knowledge (**Figure 8**). The two questions that did not show significant improvement in the NanoAdventure condition were Question 4.1/23, which was only significantly improved in the blog group; and Question 4.4/26, which improved significantly for both the blog and textbook groups. For Question 4.1/23 ("Nanotechnology involves materials that are not visible to the naked eye.") only the blog group displayed a statistically significant increase in knowledge (Textbook, $p = .1088$, Game, $p = 0.0556$). For Question 4.4/26 ("Nanotechnology allows scientists to arrange molecules in ways that do not normally occur in nature."), only the Textbook style ($p < 0.0001$) and Blog style ($p = .0078$) showed increases in knowledge.

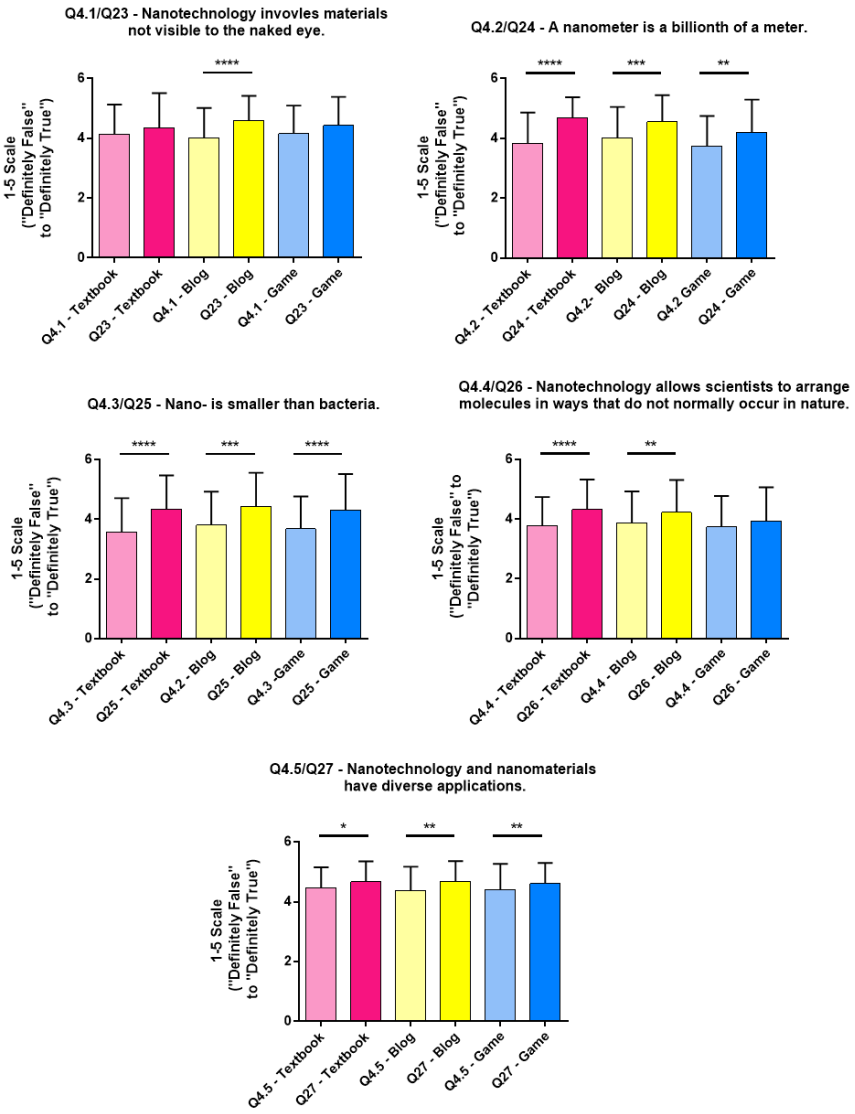

Figure 8. Responses before (muted color, left) and after (saturated color, right) on Knowledge Items. Pre-reading and post-reading results are shown for the Textbook group (pink), Blog group (yellow), and Game group (blue). Error bars show standard deviation. (* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$, **** $p \leq 0.0001$)

ATTITUDES TOWARDS NANOTECHNOLOGY

Participants were given five Likert-style statements about their attitudes towards nanoscience and nanotechnology prior to and after reading the randomly assigned text. Except for Question 5.5/23 (“Nanoscience and Nanotechnology are dangerous”), there was either an increase in the degree of agreement with the given statement or no change (**Figure 9**). For Question 5.1/Q28 (“Nanoscience and nanotechnology are useful for researchers and

scientists"), only the Textbook style group showed a significant increase. In contrast, all groups showed an increase in agreement with Question 5.2/29 ("Nanoscience and nanotechnology are useful for me"), indicating that all text styles succeeded in relating the emerging importance of nanotechnology in our everyday lives. For Question 5.4/31 ("Nanoscience and nanotechnology are interesting"), the Blog style group was the only one to not show a statistically significant increase in agreement.

Finally, Question 5.5/32 ("Nanoscience and nanotechnology are dangerous") saw an increase in agreement only with the Game Style group.

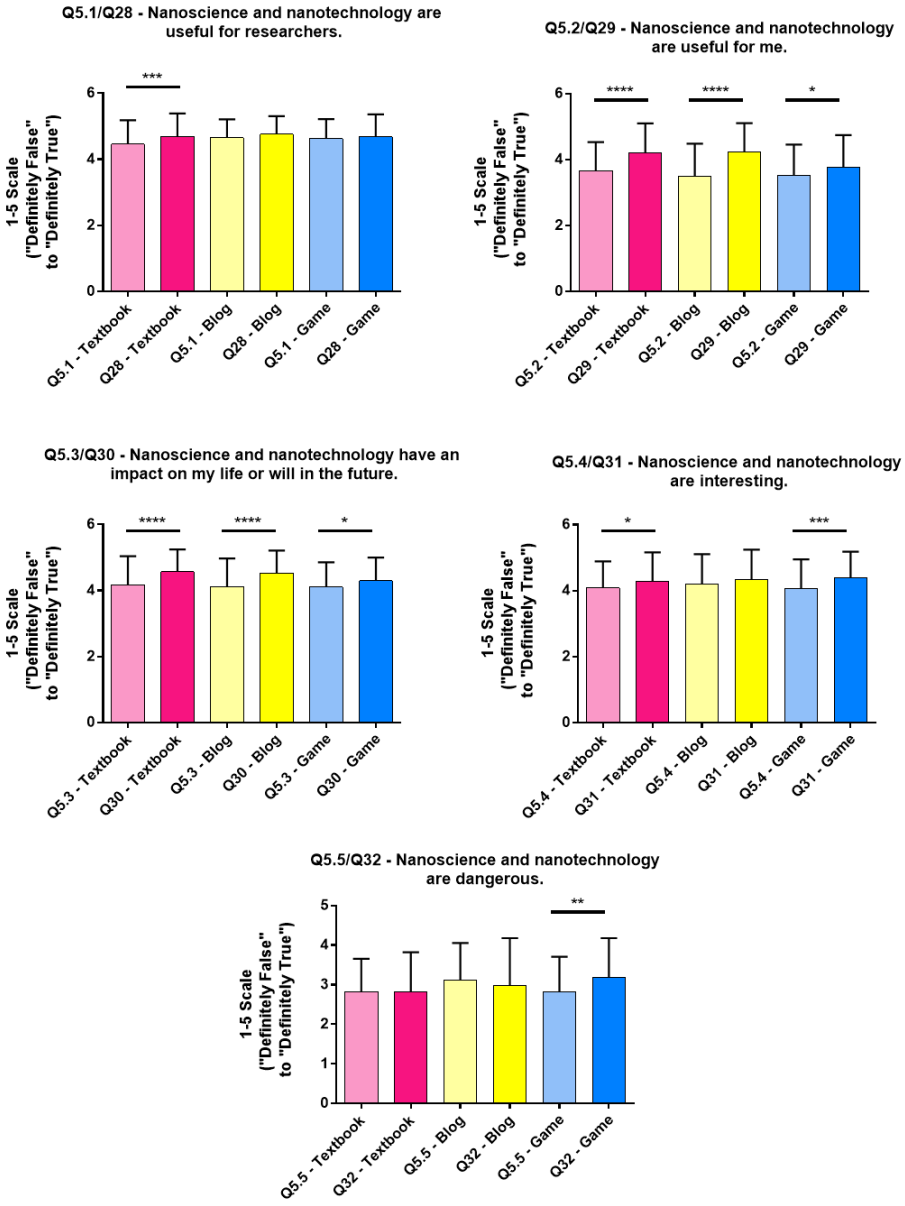

Figure 9. Responses before (muted color, left) and after (saturated color, right) on Attitude Items. Pre-reading and post-reading results are shown for the Textbook group (pink), Blog group (yellow), and Game group (blue). Error bars show standard deviation. (* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$, **** $p \leq 0.0001$)

ATTITUDES TOWARDS THE TEXT

Participants were finally asked to rank their agreement with five Likert-style questions about their feelings towards the text they had been assigned (**Figure 10**). There were no statistically significant differences among groups for statement Q33 ("I have gained knowledge through the text that I can apply to scientific thinking and problem solving") and statement Q35 ("The text made me curious about nanoscience"). However, for statement Q34 ("I enjoyed the text"), the NanoAdventure Game was rated significantly higher than the Textbook group ($p = 0.0214$), and for statement Q36 ("The text was fun to read"), the NanoAdventure game was rated the most highly and significantly higher than the textbook group. For this same question, the Blog group was also significantly higher than the Textbook group. Finally, for statement Q37 ("The text was challenging to read"), the NanoAdventure game ranked the lowest and, therefore, the easiest to read with a statistically significant difference compared to both the Textbook and Blog Groups.

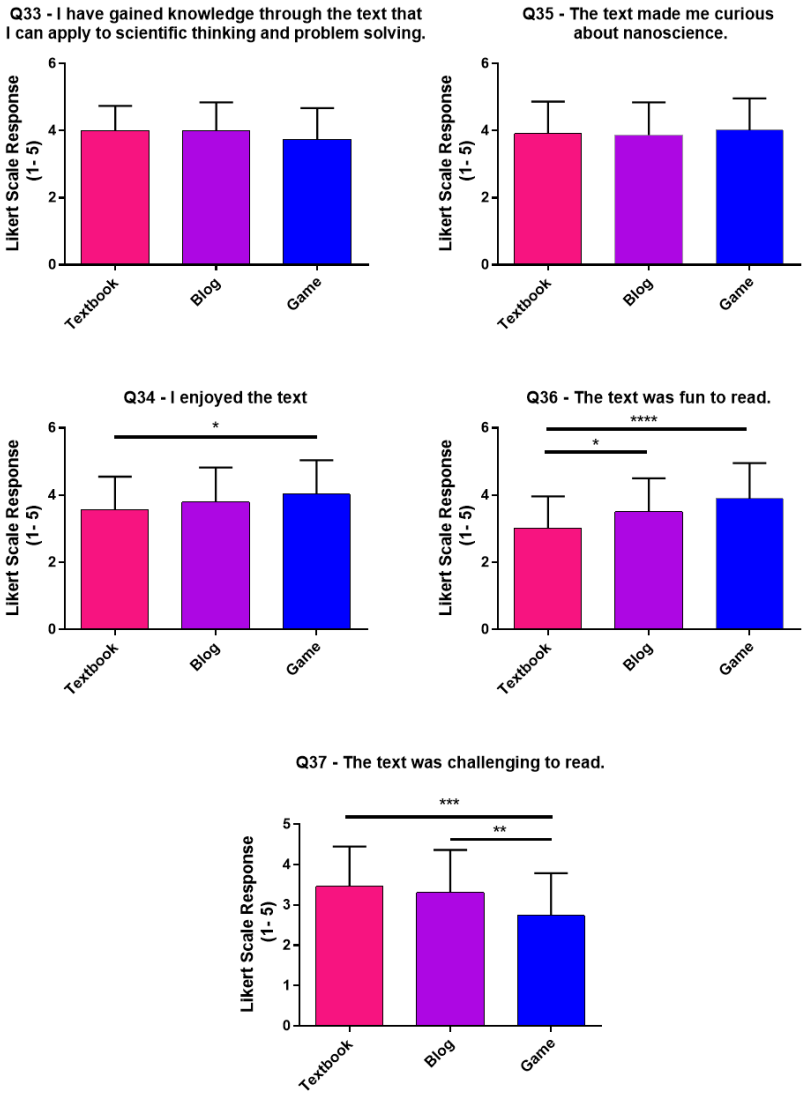

Figure 10. Responses to items concerning attitudes towards the texts. Error bars represent standard deviation. (* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$, **** $p \leq 0.0001$)

DISCUSSION

The results of this study demonstrate the strengths and weaknesses of each style of text at communicating the same topics. For “knowledge” questions, the Blog style text performed the best, with statistically significant knowledge gains for all questions. The Textbook style and Game style texts saw increases in four and three of the “knowledge” items, respectively. For Question 4.1/23 (““Nanotechnology involves materials that are not visible to the naked eye.”), only the Blog group saw improvement, although all texts covered this concept. However, it is possible that the Game play of NanoAdventure did not make it clear that the nanoscale objects

the nano-sized player-character interacted with were too small to be seen by the naked eye. For Question 4.4/26 (“Nanotechnology allows scientists to arrange molecules in ways that do not normally occur in nature.”), the Textbook style and Blog style showed increases in knowledge. In fact, the text of the NanoAdventure game does not explicitly address this concept. The success of the Blog Style and relative performance of the Game style suggests that the Blog style of text helps better relate readers to these concepts. It could also indicate that the branching pathways of the NanoAdventure game leave some knowledge gaps because one does not read all the available text in a single playthrough.

On “attitude” questions, we observed attitude changes for four of the five questions in the Textbook group, two of the five questions in the Blog group, and four of the five questions in the Game group. For Question 5.1/Q28 (“Nanoscience and nanotechnology are useful for researchers and scientists”), only the Textbook style group showed a significant increase. This may be attributed to the way the textbook passage specifically calls this out, the more traditional scientific style of the textbook-style comparison text (compared to the way the Blog appeals to everyday experiences), or an unknown factor. For Question 5.4/31 (“Nanoscience and nanotechnology are interesting”), the Blog style group was the only one to not show a statistically significant increase in agreement. This is an unexpected result as the blog style text was meant to emphasize this aspect of nanotechnology. One explanation is that, although randomly assigned, the Blog group had the highest agreement with the statement prior to the reading and therefore had less capacity to increase scores (Initial Averages: Textbook = 4.08, Blog = 4.19, Game = 4.06).

For items relating to “attitudes” towards nanotechnology, increasing agreement (mean of response) was observed for all questions except Q5.5/Q32 (“Nanoscience and Nanotechnology are dangerous”). Here, the NanoAdventure game resulted in some increase in participants’ agreements with Q5.5/Q32, which we attribute primarily to the plot of the game and consider important feedback for future projects. While characters are often in peril in stories involving the Incredible Shrinking Man motif, it may have the result of the reader/audience inferring an inherent danger that the author does not intend.

Despite modest results compared to the other text styles, it was clear that the NanoAdventure game was the easiest to read and the most fun and enjoyable text for our participants. This supports our initial hypothesis that a text-based adventure game would be more engaging than other formats because the reader becomes a reader-player and must engage with and make decisions about the path of the narrative. While not part of the study

design here, it would be interesting for future educational text-based adventure game designers to evaluate longitudinal knowledge retention (due to enhanced engagement or investment) compared to blog- or textbook-based content delivery. The NanoAdventure game was also rated as the easiest to read even though the total length of each text provided was comparable. Regarding text length, it is worth noting that video game scripts often contain word counts that one might associate with long, classic literature. For example, the English script of *Final Fantasy VII* (Square, 1997) is approximately 344,000 words[36] while *Ulysses* by James Joyce and *House of Leaves* by Mark Z. Danielewski contain an estimated 265,000 and 200,000 words, respectively. While video game players may skip passages or have varying play styles that might reduce or increase the number of words they see during play, video games in the RPG (role playing game) and visual novel style succeed at delivering long, epic stories with high word counts and yet remain accessible, fun, and engaging. While we make no conclusions about varying difficulties of any given text, we list these examples and comparisons with popular video games to demonstrate the underappreciated word count of video games and point out that video game players maybe be reading more text than they realize. Science communicators and educators might consider these methods of breaking up text and communicating through a narrative to engage the public and our students in complex topics, as an alternative to having readers passively consume the same amount of text.

For future use, we note that development of NanoAdventure was easy and accessible. The authors of NanoAdventure did not come to the project with any previous programming or game design experience. We found Twine to be a user-friendly platform with an easy-to-learn programming language (Harlowe) and a robust and responsive online community. Assets for the game, except for commissioned art for this project, culminated at a total cost of $5 USD (only music was purchased, all non-commissioned graphics had no associated costs) and were optional embellishments. Therefore, text-based adventure games are well-suited to quick development (where the time needed is primarily determined by how long it takes the author to craft a story) and low-cost development and could be implemented to teach a variety of chemical topics.

The relative simplicity of the programming languages available in Twine (Harlowe, Sugarcube) and wealth of resources suggests that it would also be feasible to have students develop their own chemistry-themed interactive texts. Write-to-learn (WTL) activities like this have been shown to enhance student engagement and learning in chemistry.[37,38]

Based on our experience with crafting NanoAdventure, we suggest that other topics in chemistry suited to an interactive text format include, but are certainly not limited to, chemical

safety, forensic mysteries, and pre-laboratory sections on new procedures and protocols. There are also several already-published chemistry escape room activities that could also inspire or be adapted into interactive fiction.[39–43]

We recommend both Twine and Ren'Py Visual Novel Engine as useful, free platforms that allow for the development of interactive fiction that can be enhanced with music and sound. Both platforms allow designers to include quizzing or puzzling to facilitate formative evaluation of student learning and instant feedback for students. Additionally, because interactive fiction is text-based and can be exported and posted as an HTML document, it can be downloaded to play offline and is better suited to screen readers than other styles of video games. NanoAdventure demonstrates that interactive fiction games have potential in chemistry education and science communication.

Future developments for interactive fiction could include puzzling and input parsing to help guide students through more complicated adventures. For interactive fiction used outside the bounds of an experiment, multiple playthroughs should be encouraged as part of the exploration and problem-solving process. Additionally, because interactive fiction is written in second person, it would be interesting to investigate how interactive fiction could help students develop their science identity and self-efficacy compared to traditional teaching texts. Because of the low cost and accessibility of development, there are many opportunities to leverage interaction fiction in the educational space.

CONCLUSION

We developed the interactive fiction text adventure, NanoAdventure, and distributed it in three languages (English, Spanish, Chinese) to compare NanoAdventure to traditional textbook-style and blog-style science communication passages. NanoAdventure performed similarly in terms of knowledge and attitude gains for participants (with a notable exception of Q5.5/Q32, concerning potential danger of nanotechnology) compared to textbook and blog style passages. However, it was clear that NanoAdventure was more accessible (i.e. less challenging and more enjoyable to read) than the text or blog style passages. Because of the low cost and relative ease of developing NanoAdventure, we suggest that interactive fiction is a promising method for science communication and a potential adaptation of writing assignments for chemistry learners.

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ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: [ACS will fill this URL in.] The English, Spanish, and Chinese comparison texts of textbook and blog style. The column statistics for the knowledge and attitude items pre- and post-reading and text attitude items of the textbook and blog style and game and the effective sizes for the knowledge and attitude items pre- and post- reading textbook and blog style and game.

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