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Nanopoly: An Interactive Board Game and Reading Activity for Enhancing Nanotechnology Curriculum in Higher Education

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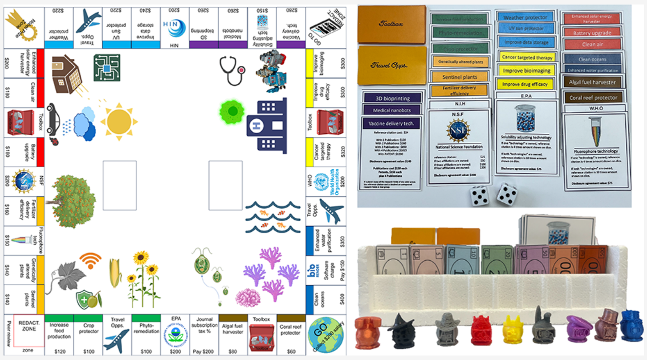

ABSTRACT: Nanotechnology plays an integral part in our society, from electronic devices, cosmetics, and food to emergent nanomedicines and nanoagriculture. Although the concept of manipulating nanoscale objects has exponentially advanced since the 60s, there is limited public perception of nanotechnology. The lack of nanotechnology public awareness can be attributed to the nascent incorporation of nanotechnology education opportunities offered at many higher education institutions. For example, in California, nanotechnology courses are offered at very few Community Colleges (~2.6%) and some State Universities (~39%). UC four-year institutions, however, do offer nanotechnology courses at an undergraduate and graduate level (90%). Herein, we created a nanotechnology-based board game paired with a blog reading as an interactive learning tool to measure impact on retaining nanotechnological concepts from the related blog for STEM majoring undergraduates. The gameplay is like Monopoly and instead uses current industry and research topics to highlight the broad applications nanotechnologies are used in. We measured the multiple-choice test performance of 51 STEM undergraduates at the University of California, Riverside, from a negative control group (board game only), a positive control group (blog reading only), and an experimental group (board game + blog reading). Multiple-choice test results showed that students who participated in the experimental group scored comparably to the positive control group. We also observed that most of the students in the experimental group self-reported greater post-enjoyment as well as greater post self-reported nanotechnology knowledge relative to the negative control group. Alternative teaching tools and styles can facilitate the advancement of nanotechnology public awareness and provide a more fun and educative learning experience than usual studying techniques like reading alone.

KEYWORDS: *Undergraduate, STEM, Interdisciplinary/Multidisciplinary, Collaborative/Cooperative Learning, Humor/Puzzles/Games, Nanotechnology*

■ INTRODUCTION

Though the concept of nanoscale science was first popularized in 1959 when Nobel Laureate Richard Feynman gave a lecture entitled "There's Plenty of Room at the Bottom" at Caltech,[1] evidence of nanotechnology has been discovered dating back to the fourth century CE with examples such as the Lycurgus cup.[2] The term "nanotechnology" was not coined until 1974 when Norio Taniguchi proposed semiconductor processes that occurred on the order of a nanometer. Taniguchi explained that nanotechnology consisted of the manipulation of materials by one atom or one molecule.[1] However, nanotechnology's peak era did not begin until Harry Kroto, Richard Smalley, and Robert Curl began researching fullerenes in 1985.[1] A decade later, Smalley, Kroto, and Curl won the Nobel Prize in Chemistry for fullerene's vast implications across the natural sciences.

Now, half a century later, the field of nanotechnology has grown exponentially due to its wide range of industrial applications in electronic devices, the pharmaceutical, cosmetic, food, and food packaging industries.[1] Nanotechnology has also been recognized as one of the most promising fields for future research, with the capacity to increase sustainability and help alleviate societal challenges such as global food insecurity and cancer treatments.[3−7] Although the field of nanotechnology has greatly developed over recent decades, the public perception of nanotechnology is in its infancy.[8,9] One of the greatest challenges that nanotechnology faces is in educating not only precollege and college students but also the public about the fundamental science, which is

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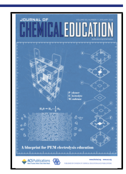

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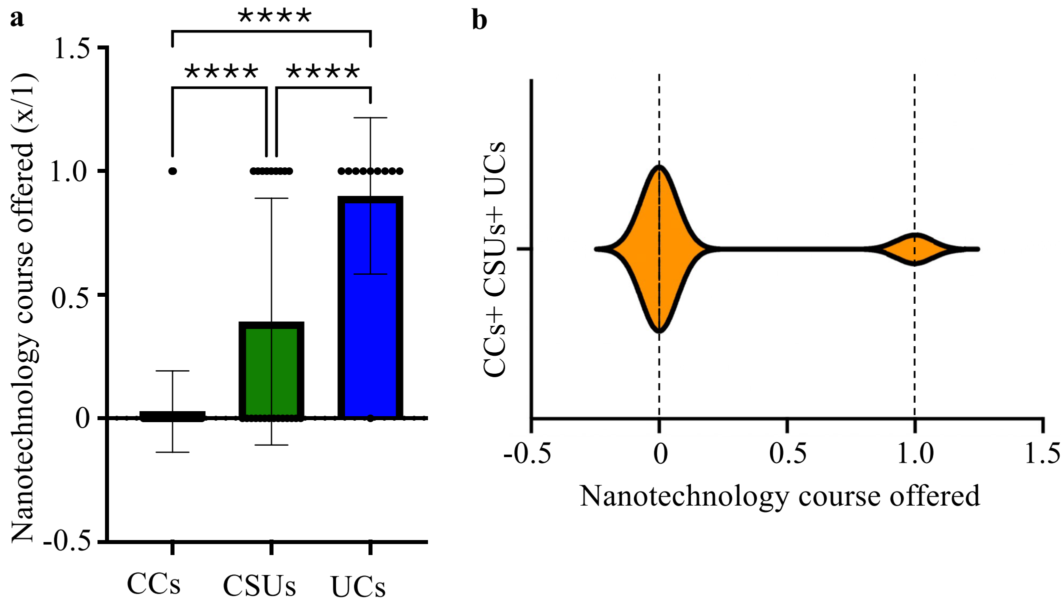

Figure 1. Bar and violin graphs of higher education Californian institutions that offer nanotechnology courses. a, Out of 116 Community Colleges (CCs), 3 offer nanotechnology courses (~2.6%), and out of 23 California State Universities (Cal States), 9 offer nanotechnology courses (~39%). University of California institutes (UCs) offer nanotechnology courses in 9 out of 10 campuses (90%). b, Across all campuses (149), approximately 14% of higher education institutions offer nanotechnology courses. For both a and b, if the campus offers a nanotechnology course, a score of 1 was allocated; if not, 0 was allocated. Statistical comparisons were performed using one-way ANOVA and Tukey's posthoc tests (*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, ****$P < 0.0001$) ($n = 10-116$).

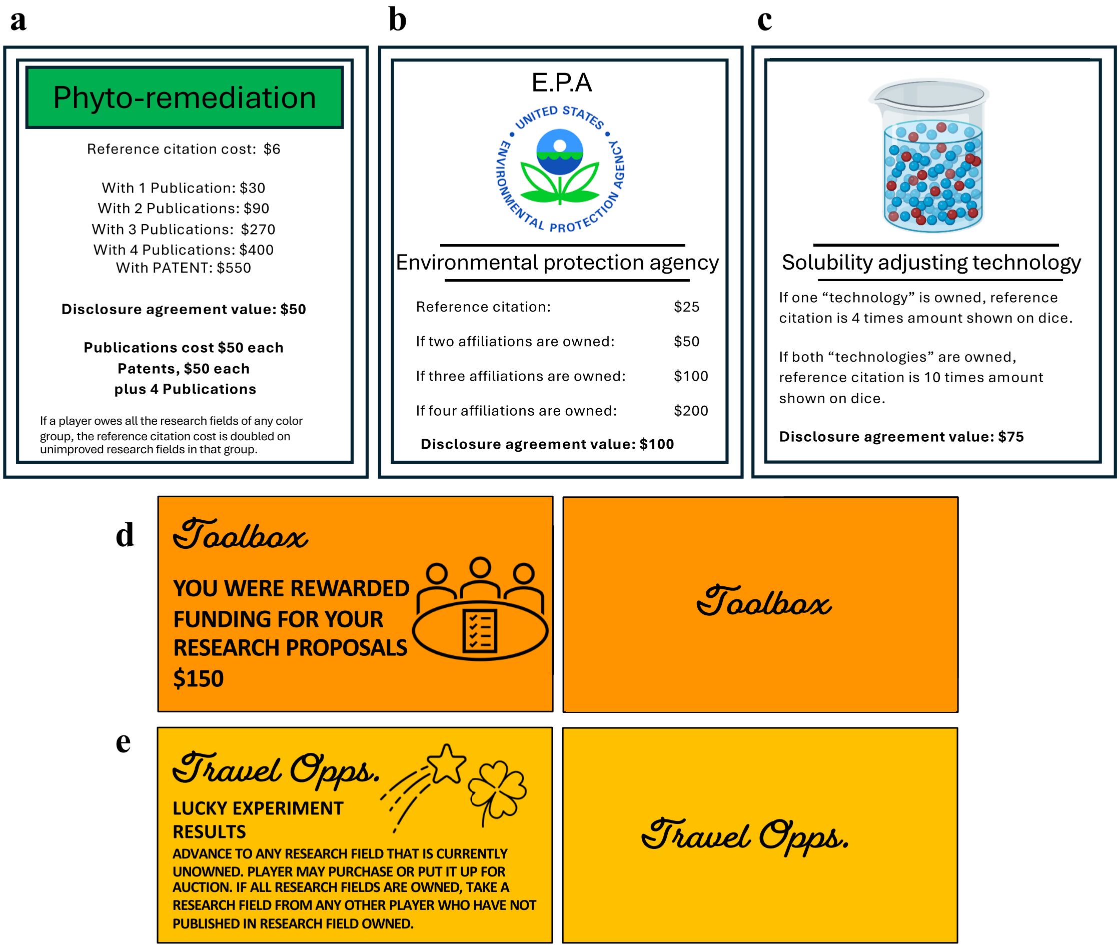

Figure 2. Example Nanopoly game cards. a, Research Field card, b, Affiliation/Organization card, c, Technology card, d, Toolbox card, and e, Travel Opportunity card.

Figure 3. Nanopoly game board. Players start at GO (lower right) and advance clockwise.

crucial for advancing nanotechnology.[10] Nanotechnology is most often taught at the graduate level, focused on such specific research questions that it may seem irrelevant to a broader nonscientific audience.[11] Moreover, educators have noted extrinsic obstacles related to disproportionate time and money required to adequately teach nanoscience, for example, through the utilization of nanoscience laboratories.[11] One reason that nanoscience education is not keeping up with the pace of nanotechnology advancements can be attributed to the highly interdisciplinary nature of nanotechnology. Its interdisciplinarity across fields like chemistry, physics, and biology means that it can be overlooked in general courses across the curriculum.[12] Furthermore, there is a disconnect between academic curriculum and the ever-evolving needs that nanotechnology industry positions demand.[13] To facilitate nanotechnology's potential future benefits, we need to provide more educational opportunities to increase awareness of the field early in STEM education and reinforce the overall positive perception of nanotechnology as the commercial applications rapidly grow.[9,14] An increase in nanotechnology curriculum at all levels of higher education can increase public awareness while exposing, motivating, and inspiring the next generation of nanotechnologists.

New topics are introduced into higher education via the addition of specialized courses. For example, looking at the California State University system, we observe that there are few nanotechnology courses offered at higher education institutions for the combined majority of higher education institutions (~14%) (Figure 1b). However, when looking at each type of institution individually (Supporting Information S12), it is evident that University of California institutions (UCs) offer nanotechnology courses more (90%) than California State Universities (Cal States) (~39%) and California Community Colleges (CCs) (~2.6%) (Figure 1a). This is not surprising, as nanotechnology courses are difficult to integrate into lower division curricula, which is the primary focus at community colleges. Yet, interdisciplinary fields like nanotechnology can motivate STEM majoring students by expanding their course knowledge and illustrating to them how nanoscience is currently utilized to improve the world. In

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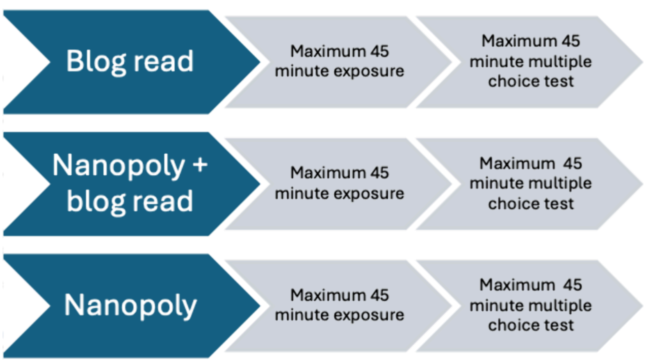
addition, these interdisciplinary topics provide opportunities for students to create connections across their coursework, strengthening their conceptual foundations.

There are many ways that nanotechnology can be introduced and taught at higher education institutions. As many others have noted, there is a need for interdisciplinarity and innovation in STEM curricula to improve student learning.[15,16] Engaging and immersive approaches, such as video games or board games, have been reported to be successful for teaching difficult scientific topics such as nanotechnology or chemistry.[17−24] With more engaging forms of teaching nanotechnology at higher education institutions, we can increase awareness of nanotechnology's potential as a tool for emerging applications in the environment, improving food and energy security, and aiding human health. This can be achieved by game-based learning activities, given the success of various other game-based tools to teach science field-related concepts. Some of the benefits of participating in game-based learning are increased engagement, deeper conceptual understanding, and improved motivation when compared to traditional studying styles.[24]

Herein, we created a board game called Nanopoly (Figure 2 and 3, Supporting Information S4−S11) with gameplay like that of Monopoly[25] and a related nanotechnology blog explaining a range of current commercial applications and research fields that use nanomaterials, including agricultural, environmental, and medical field applications. We administered a multiple-choice test to test the learning impact for 51 STEM majoring undergraduates from the University of California, Riverside across three groups: one only played the game, one only read the blog, and one did both. The groups were conceived as a positive control group (blog reading only), a negative control group (board game play only), and an experimental group (combined board game play and blog reading).

■ APPROACH



About the Board Game: Nanopoly

Game Equipment.

- Game board
- Pair of dice
- Nanoparticle game pieces (9)
- Research field cards (22)
- Affiliation/Organization cards (4)
- Action cards: Toolbox (16) and Travel Opportunity (16)
- Play money: \$1 (75), \$5 (75), \$10 (75), \$20 (75), \$50 (40), \$100 (40), \$500 (40)
- Manuscript (50) and patent (22) game pieces

Game Rules, Play, and Modifications. Nanopoly game rules (Supporting Information S11) are flexible, and participants were allowed to collectively decide (with unanimous agreement) on specific rules for play during the experiment. Nanopoly is a board game that can be played with 2−9 players. The objective of the game is to defeat other participants by depleting their currency to zero, essentially removing them from the game. Game changes that were included to hasten the gameplay included the additions of two "Lucky Experiment Result" Travel Opportunity cards, which essentially allowed players to travel to any unowned research field or take a research field card from another player that has not placed publications or patents on that research field (Figures 2 and 3).

To begin, each player chooses a game piece to represent their character in the game (Supporting Information S10). The game starts with every character on the GO space; each turn, the player rolls a pair of dice to determine how many squares to advance on the board in a clockwise fashion. The square they land on determines the possible actions for the turn.

Players can land on set colored "research fields", affiliations/organizations (EPA, NSF, NIH, WHO), or technologies (fluorophore or solubility adjustment tech) that can be purchased (if not already owned). Various other spaces may require the player to draw an action card (Toolbox or Travel Opportunity) or perform other actions (Nobel prize zone, Redact. Zone, etc.).

About the Blog

The blog was written as a companion to the Nanopoly game to highlight current research fields and applications associated with nanotechnology (Supporting Information S13). Each entry was a single paragraph and incorporated key concepts that were included in the multiple-choice test, which comprised 43 multiple-choice questions with only one correct answer (Supporting Information S1). Pre- and post- surveys (Supporting Information S2 and S3), complete blog entries, blog entry references (Supporting Information S14), and a list of all test questions are included in the Supporting Information.

Research Procedures

Approval for human subjects research was obtained by the IRB of the first author's institution. A total of 51 STEM majoring undergraduate students were recruited on campus to participate in this study. Each experimental group consisted of 17 participants ranging from a variety of STEM majoring fields.

Depending on the experimental group participants selected, they performed different tasks with similar time allocations. At the start of all experiment sessions, the lead researcher obtained informed consent signatures from participants after having explained the purpose of the study, associated risks, benefits of the study, and confidentiality measures. Participants then filled out a presurvey asking them about their STEM field, year of school, level of excitement, and self-ranked level of nanotechnology knowledge.

Phase 1 of the study consisted of either blog reading, board game play, or combined blog reading and board game play. For all groups, a maximum of 45 min was allotted for this phase, followed by an optional 10 min break. Although 45 min was not enough time for the participants in the experimental group (Nanopoly + blog) or negative control group (Nanopoly only) to finish the game, this time allocation was selected to facilitate

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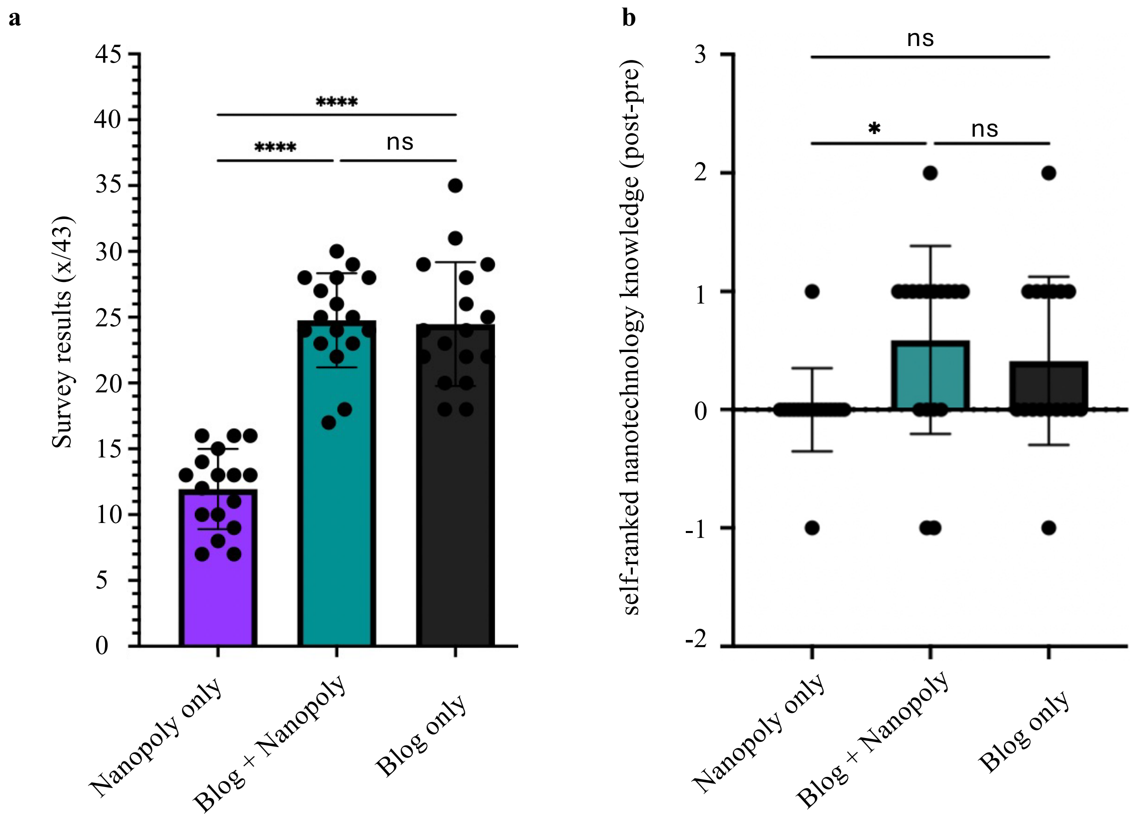

Figure 4. Multiple-choice test and difference of self-ranked nanotechnology knowledge pre- and post-exposure. a, Multiple-choice test results showed a statistically significant difference between negative control group (Nanopoly only) and both experimental (blog + Nanopoly) and positive control (blog only) groups. b, Self-ranked nanotechnology difference results (post minus pre survey) showed that experimental group participants reported a statistically significant increase in nanotechnology knowledge after experiencing Nanopoly gameplay with blog reading when compared to negative control group. Data represent means and error standard deviations. Statistical comparisons were performed using one-way ANOVA/Tukey's test (*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, ****$P < 0.0001$) ($n = 51$).

the recruitment of participants within this time frame availability. For participants reading the blog and playing the board game (experimental group), approximately 15 out of the 22 research field excerpt paragraphs were read out loud as a group. In phase 2, following the optional break, participants had a maximum of 45 min to complete a multiple-choice test (Supporting Information S1) about nanotechnology, followed by a post-study survey where they again self-ranked their level of nanotechnology knowledge and level of enjoyment. After completion of the multiple-choice test and post-survey questions, participants were awarded a $25 gift card for their participation.

Participants in the experimental group (Nanopoly + blog) participated in groups of at least two, with the lead investigator facilitating the gameplay and blog reading as the moderator. Participants in the negative control group (Nanopoly only) were either paired with another participant or played only with the lead investigator. The positive control group (blog only) participated in pairs or alone. Blank sheets of paper and pens were also provided for all groups if they wanted to take notes during phase 1. Notes were collected before starting the test in phase 2. Participants in the blog only, Nanopoly only groups, and the experimental group (Nanopoly + blog) had a maximum of 45 min to complete their phase 1 activity. For participants in the experimental group (Nanopoly + blog), blog sections were read out loud at the end of a player's turn whenever they landed on a Research Field that had not been previously read out loud.

The learning goals for the experimental group and positive control (blog only) were to familiarize themselves with hand-picked nanotechnology topics within a 45 min time frame. In essence, we compared the learning outcomes of participants who read only versus those who had reading incorporated into Nanopoly gameplay. Negative control (Nanopoly only) was treated as a baseline for general knowledge of nanotechnology for STEM majoring students.

RESULTS

To assess student learning, multiple-choice tests were administered to all groups. The experimental group (Nanopoly + blog) and positive control group (blog only) answered, on average, 25 of the 43 questions correctly. This score is significantly higher ($P < 0.0001$) than the negative control group (Nanopoly only), which answered only 12 questions correctly on average. These results indicate that both approaches effectively facilitated learning of nanotechnology concepts (Figure 4a).

Students also assessed their own nanotechnology knowledge before and after the activities. The experimental group showed an increase of an average of 1 (in a ranking from 1 to 5) in their self-assessment of their nanotechnology knowledge. This increase is a significantly greater improvement than the negative control group, who stated an average of zero increase in their self-assessed knowledge ($P < 0.05$) (Figure 4b). These self-assessment results show that the combination of the board game with reading materials provided participants with a sense

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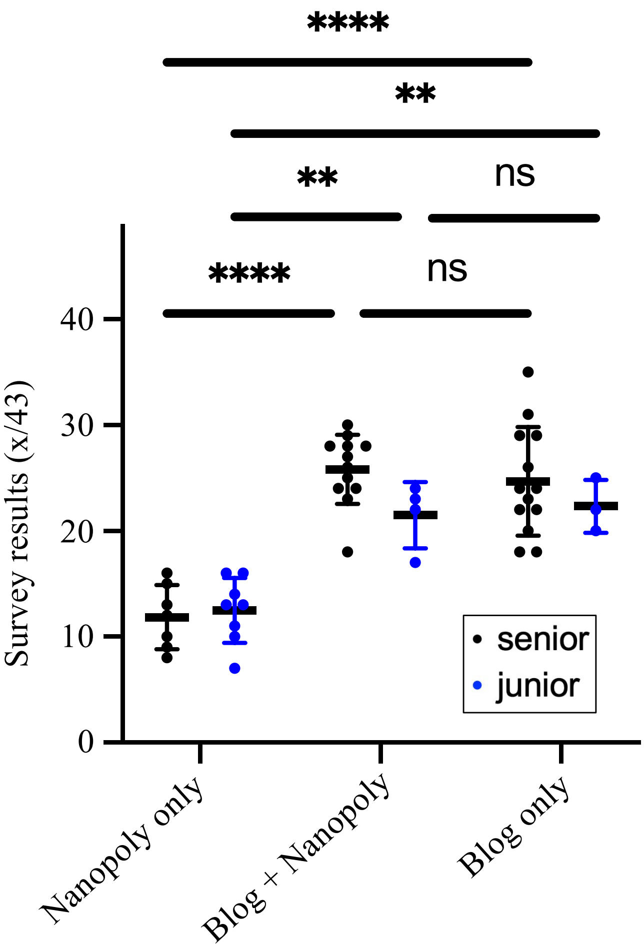

Figure 5. Comparison of measurement variable (multiple-choice test results) versus nominal variables (academic year and group participation). Multiple-choice test results showed a statistically significant difference between the negative control group (Nanopoly only) and both experimental (blog + Nanopoly) and positive control (blog only) groups for seniors and juniors. Freshman and sophomore year participants were not included due to the small sample size. Data represent means and error standard deviations. Statistical comparisons were performed using two-way ANOVA/Tukey's test (*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, ****$P < 0.0001$) ($n = 47$).

that their knowledge gain was greater than those who had only played the board game.

To evaluate the importance of participants' academic year and group assignment on their learning through this activity, the multiple-choice test scores were parsed accordingly. The juniors and seniors in the negative control group answered an average of 12 questions correctly, while juniors and seniors in the positive and experimental groups answered an average of over 20 questions correctly (Figure 5). This analysis included 32 seniors and 15 juniors; sophomores and first-year students were excluded due to insufficient sample sizes (2 participants each). The results suggest that academic year did not influence test performance; rather, the type of learning activity was the key factor determining multiple-choice test outcomes.

Student excitement and enjoyment levels are connected to engagement and motivation. In the survey, students stated their preactivity excitement and post-activity enjoyment levels as ranked from 1 to 5 as well. Initial excitement levels showed no significant differences between groups (Figure 6a). The post-activity enjoyment ratings, however, revealed that participants in both the negative control group (Nanopoly only) and experimental group (Nanopoly + blog) reported enjoyment levels above 4. This was significantly higher than the self-reported enjoyment levels for the positive control group (blog only) at an average of roughly 3 ($P < 0.0001$) (Figure 6b). The incorporation of the board game Nanopoly created a more enjoyable learning experience than traditional reading-based methods alone.

■ FUTURE WORK

As previously stated, CCs and Cal States offer nanotechnology courses significantly less than UC institutions. It is important to note that CCs offer fewer nanotechnology courses because they are often limited in the flexibility of their curricula. One possible area for future work could include a similar analysis of the STEM majoring population at the CC and Cal State levels as performed at UC Riverside to assess the impact on learning of nanotechnological concepts through Nanopoly and blogs at other levels of higher education institutions. Nanopoly and the related blog could also be incorporated into courses offered at either type of institution to increase the public's perception and awareness of current nanotechnology applications and the crucial role nanotechnology could have on globally important sectors such as agriculture and medicine. In this work, we demonstrate potential benefits of combinatorial Nanopoly game and blog activities in game-based chemistry learning tools, such as boosting self-ranked knowledge and greater enjoyment of the learning activities. Other game-based tools, NanoAdventure[17] and CheMakers,[18] showed a benefit for student learning, motivation, and engagement. A comparison between academically established game-based nanotechnology learning tools[28] can gauge Nanopoly's game and blog combinatorial added value to the field of nanotechnology education through gamification. To our knowledge, no direct comparisons between different game-based chemistry tools (e.g., board game, online game, with and without a blog) have been done, and such a comparison could help instructors select the most effective activities for the specific needs of their courses.

■ CONCLUSIONS

Nanopoly proved to be a fun way to engage STEM majoring undergraduates about current nanotechnology applications and research that was as effective as learning through reading. Incorporating the reading of informative blog text within a board game activity yielded knowledge test results comparable to blog reading participants only, with increased enjoyment ratings. This, along with improved self-ranked nanotechnology knowledge, can influence learning success and increase student engagement.[26,27]

■ ASSOCIATED CONTENT

Data Availability Statement

Supplementary information related to this manuscript is provided in the Supporting Information and at https://sustainable-nano.com/2023/09/26/play-the-game-of-nanopoly/.

Supporting Information

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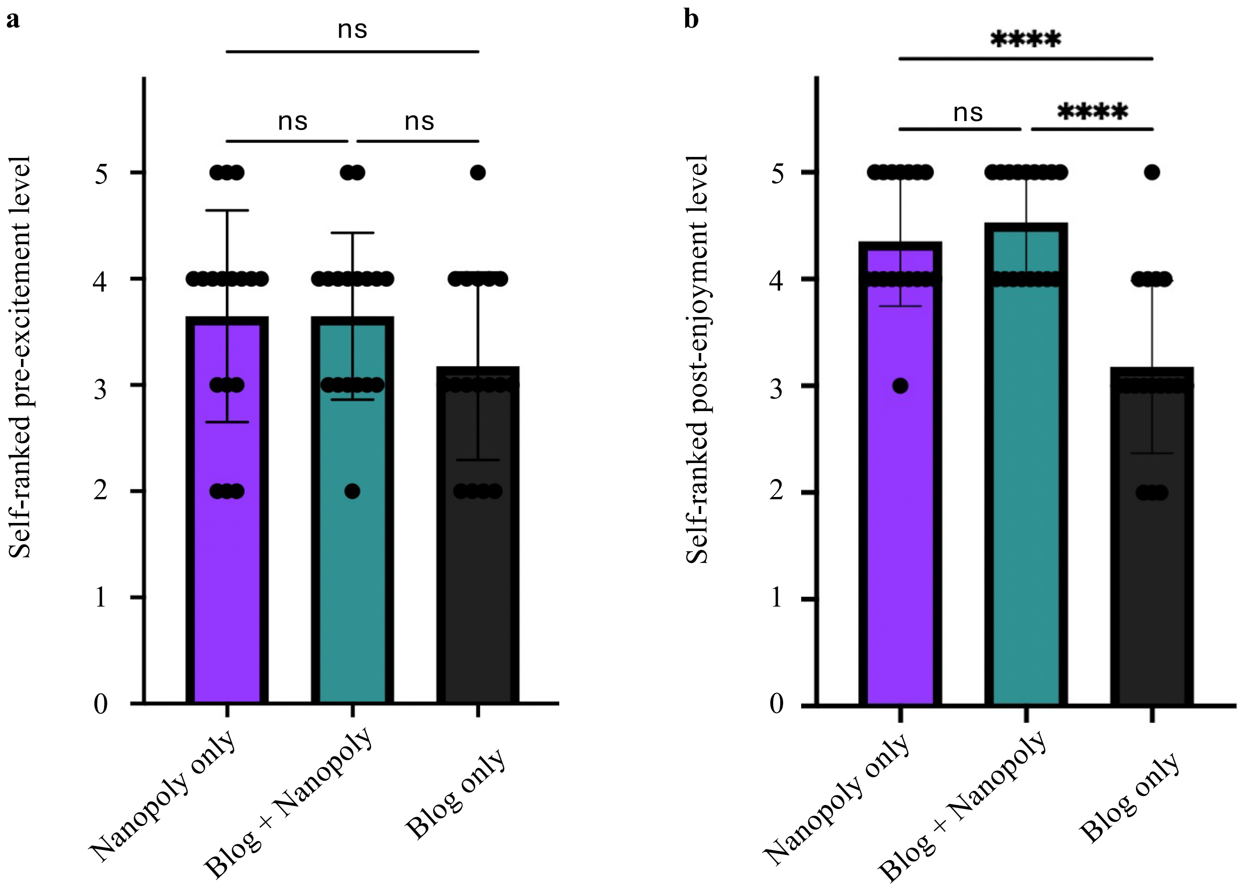

Figure 6. Self-ranked pre-excitement and post-enjoyment level results. a, Self-ranked pre-excitement levels for all groups showed no statistically significant differences. b, Self-ranked post-enjoyment level for both negative control (Nanopoly only) and experimental (blog + Nanopoly) groups yielded significantly higher levels of enjoyment than the positive control group (blog only). Statistical comparisons were performed using one-way ANOVA/Tukey's test (**P* < 0.05, ***P* < 0.01, ****P* < 0.001, *****P* < 0.0001) (*n* = 51).

Multiple-choice test, presurvey, and post-survey questions; Nanopoly game board; game cards and currency; Tinkercad links for 3D printing game pieces; game rules; table of California institutes offering nanotechnology courses; and Nanopoly research field blog entries and references (PDF)

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Notes

The authors declare no competing financial interest.

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REFERENCES

(1) Hulla, J. E.; Sahu, S. C.; Hayes, A. W. Nanotechnology: History and Future: History and Future. *Human & Experimental Toxicology* **2015**, *34* (12), 1318−21.

(2) Bayda, S.; Adeel, M.; Tuccinardi, T.; Cordani, M.; Rizzolio, F. The History of Nanoscience and Nanotechnology: From Chemical-Physical Applications to Nanomedicine. *Molecules (Basel, Switzerland)* **2020**, *25* (1), 112.

(3) Pokrajac, L.; Abbas, A.; Chrzanowski, W.; Dias, G. M.; Eggleton, B. J.; Maguire, S.; Maine, E.; et al. "Nanotechnology for a Sustainable Future: Addressing Global Challenges with the International Network4Sustainable Nanotechnology.". *ACS Nano* **2021**, *15* (12), 18608−23.

(4) Hofmann, T.; Lowry, G. V.; Ghoshal, S.; Tufenkji, N.; Brambilla, D.; Dutcher, J. R.; Gilbertson, L. M.; et al. Technology Readiness and Overcoming Barriers to Sustainably Implement Nanotechnology-Enabled Plant Agriculture. *Nature Food* **2020**, *1* (7), 416−25.

(5) Lowry, G. V.; Giraldo, J. P.; Steinmetz, N. F.; Avellan, A.; Demirer, G. S.; Ristroph, K. D.; Wang, G. J.; et al. Towards Realizing Nano-Enabled Precision Delivery in Plants. *Nat. Nanotechnol.* **2024**, *19*, 1255.

(6) Malik, S.; Muhammad, K.; Waheed, Y. Nanotechnology: A Revolution in Modern Industry. *Molecules (Basel, Switzerland)* **2023**, *28* (2), 661.

(7) Fan, D.; Cao, Y.; Cao, M.; Wang, Y.; Cao, Y.; Gong, T. Nanomedicine in Cancer Therapy. *Signal Transduction and Targeted Therapy* **2023**, *8* (1), 293.

(8) Rathore, A.; Mahesh, G. Public Perception of Nanotechnology: A Contrast between Developed and Developing Countries. *Technology in Society* **2021**, *67*, 101751.

(9) Cobb, M. D.; Macoubrie, J. Public Perceptions about Nanotechnology: Risks, Benefits and Trust. *Journal of Nanoparticle Research: An Interdisciplinary Forum for Nanoscale Science and Technology* **2004**, *6* (4), 395−405.

(10) Jones, M. G.; Blonder, R.; Gardner, G. E.; Albe, V.; Falvo, M.; Chevrier, J. Nanotechnology and nanoscale science: Educational challenges. *International Journal of Science Education* **2013**, *35*, 1490−1512.

(11) Jones, M. G.; Blonder, R.; Kähkönen, A.-L. Challenges in nanoscience education. In *21st Century Nanoscience − A Handbook: Public Policy, Education, and Global Trends*; Sattler, K. D., Ed.; CRC Press, 2020; Vol. *10* DOI: 10.1201/9780429351631.

(12) Whitesides, G. M. Nanoscience, Nanotechnology, and Chemistry. *Small* **2005**, *1* (2), 172−79.

(13) Ashcroft, J. Director's Message — Nano Education: Inspiring the Next Generation. Micro Nano Technology Education Center, 2024. https://micronanoeducation.org/nano-education-inspiring-the-next-generation/.

(14) Jackman, J. A.; Cho, D.; Lee, J.; Chen, J. M.; Besenbacher, F.; Bonnell, D. A.; Hersam, M. C.; Weiss, P. S.; Cho, N. Nanotechnology Education for the Global World: Training the Leaders of Tomorrow. *ACS Nano* **2016**, *10* (6), 5595−99.

(15) Gao, X.; Li, P.; Shen, J.; Sun, H. Reviewing Assessment of Student Learning in Interdisciplinary STEM Education. *International Journal of STEM Education* **2020**, *7* (1), 24.

(16) Bauer, J. Teaching Nanotechnology through Research Proposals. *J. Chem. Educ.* **2021**, *98* (7), 2347−55.

(17) Hudson-Smith, N. V.; Alvarez-Reyes, W.; Yao, X.; He, J.; Rodriguez, R. S.; Mitchell, S.; Matar Abed, M.; Spanolios, E.; Krause, M. O. P.; Haynes, C. L. NanoAdventure: Development of a Text-Based Adventure Game in English, Spanish, and Chinese for Communicating about Nanotechnology and the Nanoscale. *J. Chem. Educ.* **2023**, *100* (6), 2269−2280.

(18) Zhang, Z.; Muktar, P.; Wijaya Ong, C. I.; Lam, Y.; Fung, F. M. CheMakers: Playing a Collaborative Board Game to Understand Organic Chemistry. *J. Chem. Educ.* **2021**, *98* (2), 530−534.

(19) Huidobro, C.; Torralba-Burrial, A.; Montejo-Bernardo, J. M. Primary Reactions Race: Exploring Basic Chemical Reactions in a Didactic Board Game for Future Educators. *J. Chem. Educ.* **2025**, *102*, 688.

(20) Triboni, E.; Weber, G. MOL: Developing a European-Style Board Game to Teach Organic Chemistry. *J. Chem. Educ.* **2018**, *95* (5), 791−803.

(21) Li, J.; Yang, M. A.; Xue, Z. H. *CHEMTrans*: Playing an Interactive Board Game of Chemical Reaction Aeroplane Chess. *J. Chem. Educ.* **2022**, *99* (2), 1060−67.

(22) Brydges, S.; Dembinski, H. E. *Catalyze!* Lowering the Activation Barriers to Undergraduate Students' Success in Chemistry: A Board Game for Teaching Assistants. *J. Chem. Educ.* **2019**, *96* (3), 511−17.

(23) Franco-Mariscal, A. J.; Oliva-Martínez, J. M.; Blanco-López, Á.; España-Ramos, E. A Game-Based Approach to Learning the Idea of Chemical Elements and Their Periodic Classification. *J. Chem. Educ.* **2016**, *93* (7), 1173−90.

(24) Byusa, E.; Kampire, E.; Mwesigye, A. R. Game-Based Learning Approach on Students' Motivation and Understanding of Chemistry Concepts: A Systematic Review of Literature. *Heliyon* **2022**, *8* (5), No. e09541.

(25) *Monopoly*. Hasbro, 1996.

(26) Mangels, J. A.; Butterfield, B.; Lamb, J.; Good, C.; Dweck, C. S. Why Do Beliefs about Intelligence Influence Learning Success? A Social Cognitive Neuroscience Model. *Social Cognitive and Affective Neuroscience* **2006**, *1* (2), 75−86.

(27) Kang, X.; Wu, Y. Academic Enjoyment, Behavioral Engagement, Self-Concept, Organizational Strategy and Achievement in EFL Setting: A Multiple Mediation Analysis. *PloS One* **2022**, *17* (4), No. e0267405.

(28) UW-Madison MRSEC Interdisciplinary Education Group. *NanoVenture: The Nanotechnology Board Game*. https://chemistry.beloit.edu/edetc/supplies/nanoventure/NVgamerules_booklet.pdf.

https://doi.org/10.1021/acs.jchemed.5c00894
J. Chem. Educ. 2026, 103, 318−325