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Storytelling as Pedagogy: The Power of Chemistry Stories as a Tool for Classroom Engagement

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ABSTRACT: Storytelling in chemistry as a pedagogical tool provides an alternative learning format for students to discover more about the people behind STEM (Science, Technology, Engineering, and Mathematics) innovations that impact our society. However, there is a dearth in the literature on what influence storytelling pedagogy could have on STEM classroom. Our study examines the influence of storytelling as a pedagogical tool on students' understanding of the importance of JDEI (Justice, Diversity, Equity, and Inclusion) in a social seminar course with the theme "Equity and History of Science." Our storytelling study has a small sample size with 13 students pursuing STEM majors. We describe the impact of screening four narrative films celebrating the significant contributions of chemists Professor Alice Augusta Ball, Dr. Saint Elmo Brady, Dr. Percy Lavon Julian, and Dr. Bettye Washington Greene in the social science seminar course. Our framework is aligned with Bell and Roberts' Storytelling Project (STP) Model, which focuses on creating a counter-storytelling community and using various story types (stock stories, concealed stories, resistance stories, and emerging/transformative stories) for engagement. Our study examined the complex interaction of many factors in the course, such as narrative films watched, student reflections on narrative films, in-class activities related to films and course readings, focus group interviews with students in the course, and an individual interview with the course instructor. Our results suggest that these films had a positive influence on all students in the course as it relates to representation in STEM, bridging of JDEI, and chemistry concepts. By learning about the stories of these chemists, it made learning more engaging and realistic, and critical thinking thrived. We will also discuss a practical example of how STEM faculty can use strategies that leverage popular films such as Marvel Studios' *Black Panther*, where the fictional element vibranium (Vb) is an important protagonist for student engagement in chemistry. Our study has potentially global relevance for practice as it relates to teaching pedagogy in STEM classrooms and the retention of students of color pursuing STEM majors.

KEYWORDS: *Upper-Division Undergraduate, Interdisciplinary/Multidisciplinary, Communication/Writing, Student-Centered Learning, Women in Chemistry*

INTRODUCTION

Why are so few women and people of color represented in STEM (Science, Technology, Engineering, and Mathematics) fields? The challenges to effectively address justice, diversity, equity, and inclusion (JDEI) within the STEM fields are well-documented in current research when exploring the lived experiences of undergraduate women and students of color.[1] A new study investigated an association between the low performance of students in introductory STEM courses and failure to obtain a STEM degree at six public universities with the R1 or R2 classification.[2] The researchers concluded that this association is statistically higher for historically underrepresented students and reported that Black female students had a 28% probability of completing a STEM degree compared to those of other student populations. In addition, the researchers also recognize that the overall classroom experience includes several components including the instructor variables, specifically "whether one holds a fixed versus growth mindset."[2] Thus, there are many societal and contextual factors that influence the success of marginalized students in STEM, one being representation within these fields. However, we propose that the intentional inclusion of STEM professionals from marginalized communities using storytelling in course curricula could have a positive impact on historically underrepresented student populations as it relates to envisioning themselves in these fields.[3,4]

An understudied area of research in STEM fields is the influence of pedagogical teaching practices such as storytelling and the history of science on students of color in the classroom. Storytelling in STEM as a pedagogical tool provides an alternative learning format for students to discover more

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about the people behind the STEM innovations that impact our societies.[5,6] Our study examined the incorporation of storytelling as a pedagogical tool that influenced students' understanding of the importance of JDEI in a social seminar course with the theme "Equity and History of Science." Important learning goals for the course included the students learning about inclusive stories within STEM and becoming effective storytellers of their own journeys in STEM as emerging scientists from marginalized backgrounds, which led to an enhanced understanding of JDEI within the STEM field. Herein, we describe how we used four narrative films for class discussions focused on the intellectual achievements of chemists, Drs. Bettye Washington Greene, Saint Elmo Brady, Percy Lavon Julian, and Alice Augusta Ball. Specifically, this study addresses two key research questions:

1. What perceptions do students draw from engaging in storytelling or watching documentaries in chemistry related courses?
2. How should chemistry educators effectively incorporate specific narratives and apply it in course content?

Culturally Relevant Pedagogy in Chemistry

Culturally relevant pedagogy (CRP) is a theoretical framework that focuses on both student achievement and acceptance of their cultural identity. Gladys Ladson-Billings, who first introduced the CRP term in 1995, proposed three pillars of CRP, namely, student learning, cultural competence, and critical consciousness.[7] Recent publications focused on CRP in chemistry have addressed many diverse topics. These topics include computer-based VSEPR (valence shell electron pair repulsion) theory lessons targeting East African high school students in Kenya and Tanzania. The researchers focused on medicinal plants commonly used in East Africa for the development and implementation of CRP chemistry focused lessons to engage students in the classroom.[8] Investigators have also developed CRP chemistry units targeting students enrolled at a tribal college in Utqiaġvik, Alaska focused on the cultural relevance of the Arctic region and the impact on the Indigenous communities in northern Alaska.[9] The CRP lesson focused on changes in snow and ice chemistry due to the impact of global warming. These CRP chemistry examples and our current study align with the pillars of CRP, specifically by enhancing the critical consciousness of undergraduate students.

Storytelling in Chemical Education

Previous studies focused on storytelling in STEM education have been reported in the literature.[4−6] Collins[4,5] reported various approaches for aligning the stories of BIPOC (Black, Indigenous, and People of Color) chemists with course content for student engagement. Chari et al.[10] developed an undergraduate organic chemistry course focusing on transition-metal catalysts in modern drug discovery. The course highlighted "the empowering stories of chemists from underrepresented backgrounds in leadership positions" and successful career pathways in chemistry. Younge and colleagues[11] utilized the PBS documentary, *Forgotten Genius*, in the chemistry curriculum on the remarkable career of eminent organic chemist, Dr. Percy Julian. The researchers reported an increase in the student knowledge about the significance of science. Babb and Austin[12] described using the 2020 documentary, *Picture a Scientist* in a special topics course with the theme, "chemistry and racism" for general chemistry students. Winston[13] describes the field of chemistry as "an excellent candidate for a narrative approach, as content naturally flows from one idea to the next." Furthermore, these articles relate to our study because in teaching through storytelling, we are able to make deeper connections on diverse topics with students in the classroom. Storytelling engages the audience and situates them in concepts with complex messages that are sometimes lost because one might be focusing on one concept when learning is multidimensional. By incorporating storytelling in the classroom experience and teaching students how to develop their own story, these techniques and concepts further justify how storytelling engages its audience to reflect and critically engage by unpacking learning beyond simple visual entertainment.

Course-Based Undergraduate Research Experience

The concept of course-based undergraduate research experiences (CRE, also known as CURE) has increased significantly in American higher education and has shown great impact in both STEM and non-STEM disciplines.[14−16] In the simplest form, its practice consists of fostering an active, problem-solving learning environment by incorporating original research within the course curriculum.[17,18] Because the framework of CRE is embedded in the course itself, it is considered to be an inclusive teaching practice that engages all students in the class. CRE has been recognized as an academic intervention that promotes positive learning experiences and improved attitudes such as academic agency, confidence, and ownership in original discovery.[19−23] Respectively, CRE broadens the participation in research activities through accessibility to research opportunities for all categories of students and disciplines, especially historically underrepresented students in STEM education. Lastly, CRE merges teaching and research by incorporating both pedagogical and research goals in the classroom.[24−26] Therefore, by incorporating culturally relevant pedagogy, storytelling, and course-based undergraduate research into the classroom experience, we believe practical applications of these theoretical insights will further establish its significance for examining how students engage and respond to project ownership, understanding scientific concepts, as well as developing STEM self-perceptions, which further promotes inclusive teaching and learning.

METHOD

Conducted during the Spring of 2022, this qualitative study employed a descriptive case study approach to address our research question. Case study is a research approach that investigates a contemporary phenomenon in depth and within its real-life context.[27] Our study was descriptive in nature due to the amount of data collected in various forms over the course of the Spring 2022 semester, allowing us to generate a description of the influence of storytelling pedagogy on the student experience.[28] However, to successfully conduct a case study, we must define the bounded system that framed our study. A bounded system within case study research can also be described as the unit of analysis in the study that allows researchers to collect a finite amount of data due to identified parameters of what the study is and what it is not.

For this particular study, our bounded system, the specific parameters of our study, was a social science seminar course at Lawrence Technological University (LTU), entitled "Equity and History of Science", taught by one of the members of the

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research team (Dr. Sibrina Collins). This course was designed to utilize storytelling as a pedagogical tool for classroom engagement. Within this course, we specifically explored the complex interaction of many factors in the course such as narrative films watched, student reflections on narrative films, in-class activities related to films and course readings, focus group interviews with students in the course, and an individual interview with the course instructor.[29] From the data points collected, we were able to examine the use of storytelling as an intervention strategy to deepen a student's engagement, persistence, and self-perceptions as a member in the STEM community.

Our storytelling framework for the study is aligned with Bell and Roberts' Storytelling Project (STP) Model,[30] which focuses on creating a counter-storytelling community and using various story types (stock stories, concealed stories, resistance stories, and emerging/transformative stories) for engagement. Bell and Roberts describe stock stories as narratives society considers to be important and meaningful and serve as a foundation for understanding how racism operates within society. Concealed stories are largely unknown narratives that are generally hidden from mainstream, but "exist alongside stock stories." The resistance stories describe how individuals resisted bias and racism. Finally, emerging and transformative stories are new narratives that have been developed within a storytelling community.

Context of Our Bounded System and Methods

The social science seminar course, our bounded system for this study, with the theme "Equity and History of Science," was a hybrid course taught during the Spring 2022 semester on the campus of LTU, a private institution in Michigan. This course was designed using the three pillars of course-based undergraduate research experience (CRE),[29] namely: (1) discovery through scholarly practices; (2) inclusive collaboration; and (3) communication of relevance. There were 13 students enrolled in the course, specifically 10 engineering majors and three architecture and design majors, who all participated in the study. In this course, 46% of the students were White; 54% were students of color, which includes Black or African American, Asian American, and international students. Men represented 62% of the students enrolled in the course, compared to 38% women. Two books were required reading for the course, specifically *The Alchemy of Us*, authored by Dr. Ainissa Ramirez, and *Hidden Figures*, authored by Margot Lee Shetterly. Both of these books were selected because of the focus on inclusive stories in STEM. During the course, Dr. Ramirez virtually visited the class, which provided the students with a unique opportunity to engage with an accomplished book author.

Over the entire semester, students in the course were required to write, direct, and produce a five min narrative documentary focused on STEM-based concepts as an alternative to a traditional written final examination. This provided a unique opportunity to help students shape their academic identity and self-reflective STEM journey. Thus, the student films are CRE-based projects. All class assignments were provided by using the Canvas platform. In order to provide support for students creating their own documentaries, a CRE undergraduate researcher (Logan Daniher) served as a peer-mentor sharing best practices for creating engaging narrative films for the culminating course project. The guidelines for the CRE-based projects including a rubric are provided in the Supporting Information. The students provided input regarding the criteria for the rubric used for the assessment of the CRE-based projects. Specifically, we completed an in-class activity titled "Criteria for Evaluating Documentaries" using a Google Doc in February 2022 to gather feedback from the students.

To engage all students in the hybrid course, a class "Google Doc" was created to allow students to respond in real-time during class discussions after watching a narrative film or reading an article. Specifically, students were asked to write what they believed was the main point of the story or a question that came to mind for class discussion.[6] Using the "flipped classroom" approach, each student was given an opportunity to lead a discussion based on their own reflections. To understand more of the instructor perspective of intentionally utilizing storytelling pedagogy throughout the course of the semester, a 45 min, semi-structured interview was conducted with the course instructor. To conclude the data collection process, researchers conducted two focus group interviews with students in the course during week twelve of the semester. For flexibility and convenience, one focus group was led in-person, while the other was led online using the Zoom platform. Each focus group on average lasted for approximately 30 min.

Data Analysis

Our data analysis process was ongoing throughout the semester in which data were collected. We first began our analysis by analyzing each student's individual critical reflection of the films viewed in class. During this review, researchers individually looked for recurring themes among students' reflections. Ideas that were deemed as outliers in comparison to shared themes were noted but not included in the overarching themes identified. In addition to identifying recurring themes, researchers engaged in peer debriefing of themes they found individually to determine what themes were consistently identified across our analyses. After reviewing our themes, researchers identified three themes that will be reviewed further in our results and discussion. To identify themes, we examined how each student's response answered our research questions and the overall study goal. We were particularly interested in students' discussions around developing their own STEM identities, how they define characteristics aligned with a successful STEM identity, the overall societal impact on the experiences that chemists of color need to navigate in the academy, and how their scientific achievements are (under)represented and discussed within the discipline.

RESULTS AND DISCUSSION

The Intervention: Engaging in Documentary Screenings

As noted in literature, the role of documentaries serves as an important teaching tool that engages the student and maximizes the academic learning experience.[31,32] These immersive learning activities engage students to access the lived experiences of scientists and use these approaches to unpack learning. For example, each documentary watched was followed by open-ended questions in class to serve as an academic strategy and practice to engage in critical thinking and to check for understanding. By doing this, students were able to identify key concepts and techniques needed to create their own captivating documentary. Students watched and discussed in class: *Twenty Whites & One Other*,[33] *The Ball*

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Method,[34] and *Forgotten Genius*,[35] which focused on the achievements of Dr. Saint Elmo Brady, Professor Alice Augusta Ball, and Dr. Percy Lavon Julian, respectively.

Brady was the first African American to earn a PhD in chemistry in the United States in 1916 from the University of Illinois at Urbana−Champaign.[36,37] Dr. Richard Evans, a former student of Dr. Brady when he was enrolled as a chemistry major at Tougaloo College, an HBCU in Mississippi, described him as "a man of very neat appearance, piercing eyes behind his bifocals, silver-white-wavy hair, and olive complexion. His pipe and robust laugh all seemed to reinforce his larger-than-life image, which was not at all suggestive of his seventy years."[37] Ball was a young chemist, who developed the first viable treatment for leprosy in the early 20th century, which was a serious public health crisis during that time period.[38,39] Julian, a brilliant organic chemist, is the fourth African American to earn a PhD in chemistry and developed treatments for glaucoma and arthritis.[39] When reflecting on the content of the documentary, students developed profound questions related to issues of JDEI. Selected student responses after watching *Twenty Whites& One Other* included the following:

- *One question that comes to mind is the environment that Saint Elmo Brady was in while attending University of Illinois to receive his PhD in chemistry, especially being the first. Was it uncomfortable? Were his fellow students nice to him? Were professors harder on him? This is a huge accomplishment, but the part other people do not know or see is the behind the scenes work that went into getting his degree.*
- *They spoke about Saint Elmo Brady's motivation being to change the world; one question I have is what instilled this motivation so strongly within him. Also when first beginning his pursuit of higher education. I wonder what mentors he had that guided him through the undergrad and graduate program being the first African American PhD in Chemistry, because no organizations for people like him have been established yet.*
- *How did St. Elmo Brady overcome institutional racism in higher education and beyond? Despite the barriers he must have faced, he became the first black PhD graduate in Chemistry and established a successful, inclusive chemistry program to give back to his community.*

Students shared similar thoughts when reflecting on the journey of Professor Alice Augusta Ball. Selected student responses after watching *The Ball Method* included the following:

- *If Alice Ball was given the full credit of her work when she made the discovery, what other brilliant discoveries could she have also made after? Were there any other discoveries she made that have been covered up?*
- *How can we make sure that individuals get credit for their work fairly in terms of a legal aspect? I find this interesting even today especially with intellectual property (patents). Is our current system good, or can improvements be implemented?*
- *How common was it for someone to steal someone else's work without giving any credit back in that time? Has it gotten worse in today's society? How much of this is still hidden from us?*

The reflections of students were more pronounced in the third documentary watched in class. Selected student responses after final screening of *Forgotten Genius* included the following:

- *After watching the documentary one thing that really stood out to me was the bombing outside of Dr. Julian's house and how he and his son would sit up in the tree late at night and have long conversations about how the people trying to hurt their family were making bad decisions and they were angry that they were in the neighborhood only due to their race. While the little girl down the street asked her father why those people were trying to bomb her friend's house, he just said he did not have an answer to give her. Why do we shield children from very real problems? Especially if educating at an early age could prevent more racially motivated crimes?*
- *With all the impressive scientific findings and developments along with the social change and activism that Julian was able to create, it makes me sad that the ending of the video showcased and brought to light the way he recounted his pursuits as incomplete or inadequate. My question is, I wonder what Julian intended for himself and what outcomes would have caused him to reflect back and be more satisfied with his discoveries; what was his ideal scientific journey? And was this based on the reality of trials that he had to have known he would have faced at the time due to his color?*
- *I find it very interesting how the company for which he worked seemed to not trust him enough to do anything more than paint chemistry even after his hormone discoveries. Why would they want to limit him? And why would they not trust him enough, at that point, to make them more money and continue research?*

After much practice and modeling, students then moved on to watch and discuss a documentary that was written, directed, and produced by a fellow peer. This experience allowed students to see an example of what was expected of them by the end of the semester as well as address any concerns of producing their own STEM story. The CRE final project to write, direct, and produce a documentary film served as a teaching tool to help shape a STEM academic experience for students enrolled in the course.

The documentary, *Inclusive Stories in Science: Celebrating Dr. Bettye Washington Greene (BWG)*[40] was written, directed, and produced by an LTU media communications major (Logan Daniher) and screened on the last day of class (April 28, 2022) in the semester. Greene, born in Palestine, Texas on March 20, 1935, earned an undergrad degree in chemistry from Tuskegee Institute (now known as Tuskegee University), a historically Black college and university (HBCU), in 1955.[41,42] In 1960, she enrolled in the doctoral program in the department of chemistry at Wayne State University (Detroit, MI), earning her PhD in physical chemistry under the direction of Professor Wilfried Heller in 1965 with a dissertation titled, "Determination of Particle Size Distributions in Emulsions by Light Scattering."[43] Upon graduation, she was hired as a research chemist with the Dow Chemical Company in Midland, Michigan, focusing on latex and polymer chemistry. Greene was later promoted to senior research chemist in 1970, retired in 1990, and has several registered patents and publications in high-impact journals, with over 100 citations.[42,44] After watching the 8-min documentary, the students were given the following prompt: *After watching the new Lawrence Tech student documentary written, directed, and produced by Logan*

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Table 1. Themes Connection to Codes

Themes	Definition	Codes
Reality of STEM careers for marginalized people	Reality of STEM careers is accessible for marginalized people	Self-Perceptions; How do we negotiate our roles; Life roles (e.g., chemist, colleague, parent); Racism; Empathy toward others
Importance of mentorship and support	The importance of mentorship and support comes from communities and environments that cultivate support systems and challenge to do better	Persistence; Barriers and Career Challenges; Selection of a Doctoral Program; Why study chemistry; Mentorship and supporting environments;
Unaccounted for scientific accomplishments	URM STEM contributions and unaccounted accomplishments impact society, should be celebrated and acknowledged.	STEM Contributions in Society; Celebrating Career achievements; Innovations in science; Intellectual Property and Proper Credit for Scientific Work

Daniher, briefly write down the main point of the story. What question comes to your mind after watching the video? Selected student responses after watching the documentary about Greene include the following:

- *I think the main point was to celebrate the life of Dr. Bettye Washington-Greene and all of her wonderful accomplishments. The interview with her daughter was very heartfelt, and hearing her say she just hopes she is proud of her today was very touching. It was enjoyable listening to her mother's story and how even when she was baking, she would call everything by its scientific name because that was her passion.*
- *My questions about the documentary mainly have to do with the choices of Dr. Greene. I am wondering primarily why she chose to study her PhD at Wayne State in Detroit, MI, being from Texas and initially studying her undergrad in Alabama. Around that time, I am assuming these places were centers for African Americans, did that make them more favorable/welcoming for African Americans seeking higher education?*
- *The main point of this student documentary was to highlight the life and achievements of Bettye Washington-Greene. She continued to break barriers for what African American women could achieve. She was able to receive a PhD at Wayne State University and finish her career at Dow Chemical, where she spent 25 years creating great strides in Latex. The one thing I did not really notice from the video is the struggle before the success; what kind of struggles might she have faced during her time in this field?*
- *This documentary follows the life of Dr. Bettye Washington-Greene. She was a brilliant scientist, peer, colleague, and wife and mother who contributed significantly to Wayne State University where she earned her PhD and Dow University where she discovered breakthroughs in Latex. In both of these positions, she was the first African-American woman.*

Within the written responses after each screening, researchers identified emerging patterns representing students' perspectives of the historical experiences of each documented chemist in relation to their current journeys as STEM students. With the diverse student voices included in the study, emergent themes became evident: (a) the reality of STEM careers for marginalized people; (b) the importance of mentorship and support; and (c) unaccounted for scientific accomplishments.

In Table 1, a summary of the analysis represents the coding scheme that was used to categorize, identify patterns, and draw conclusions of the emergent themes.

It is important to note that these diverse perspectives support our research investigation which was to examine how we make sense of our learning, strategies to motivate and help others persist in STEM while valuing the innovations of science and their lived experiences from underrepresented contributors in the field. By learning about the stories of these chemists, it made learning more engaging and realistic, and critical thinking thrived.

In addition, a student response regarding Greene focused on why she attended Wayne State University for doctoral studies, given that she was born and raised in the segregated south. Greene was also offered admission to the doctoral program at Massachusetts Institute of Technology (MIT), but accepted the offer from Wayne State University because of the financial package provided.[42] It is well-documented that African Americans would often earn undergraduate degrees from HBCUs, then pursue graduate studies in the northern states because there were no options in the southern states at the time.[45] Moreover, Wayne State University was the leading producer of African Americans earning PhDs in chemistry in the 1960s.[46]

Not surprisingly, student voices regarding Professor Alice Augusta Ball's story focused primarily on giving proper credit for scientific work, intellectual property, and publications. Professor Ball developed the first viable treatment for leprosy, specifically isolating the ethyl esters from chaulmoogra oil, but did not live to see the impact of her work. Four years after her death, Dr. Arthur Dean, then president of the College of Hawaii, and Dr. Richard Wrenshall, chemistry professor, published a paper in 1920 in the prestigious *Journal of the American Chemical Society* and failed to mention Professor Ball's contributions.[47] The student responses regarding Ball's scientific contributions being stolen from her could certainly demonstrate both sympathy and empathy toward her while also acknowledging inequity within the STEM fields, which illustrates the importance of JDEI in relation to the STEM profession.

The student reflections after watching the films about Drs. Saint Elmo Brady and Percy Lavon Julian were also very compelling. Regarding Brady, the student responses focused on effective mentoring and how he overcame racism to become the first African American to earn a PhD in chemistry. However, the reflections about Julian were fascinating. "With all the impressive scientific findings and developments along with the social change and activism that Julian was able to create, it makes me sad that the ending of the video showcased and brought to light the way he recounted his pursuits as incomplete or inadequate," writes one student. The main point here is that because of the racist barriers Julian faced throughout his career, he never became the chemist that he wanted to be. In addition, another student focused on the bombing of Julian's home, as described in the film. The student reflects, "While the little girl down the street asked her father why those people were trying to bomb her friend's house, he just said he didn't have an answer to give her. Why do we

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shield children away from very real problems? Especially if educating at an early age could prevent more racially motivated crimes?" This response is captivating because the student is actually suggesting a solution to address racism in society, again emphasizing the significance of including JDEI discussions and concepts in STEM focused classroom environments.

In summary, our results indicate that engaging in storytelling both to learn from as a teaching practice and to deepen learning fosters engagement and active learning. Our approach, which is a strategy to improve DEI in the classroom, allows historically underrepresented chemists to be the "protagonists" of the lessons being discussed with students. In STEM courses where some concepts can be difficult to understand, discussing the lived experiences of scientists from marginalized backgrounds and exploring the intellectual contributions and achievements actually allow students from historically underrepresented backgrounds to "visualize" themselves in STEM fields like chemistry.[3,4] Therefore, from our study, we offer ways in which we connect our unsung heroes in science to chemistry concepts that meet curricular expectations.

CONNECTIONS TO CHEMISTRY CONCEPTS

As chemists, one may wonder why or how to incorporate storytelling pedagogy and JDEI into the chemistry course content that is required for students to learn. Here, we provide examples of how the stories of scientists of color and their contributions can be intentionally infused into course curricula. The examples provided demonstrate an authentic way to incorporate lessons on JDEI and the inclusion of marginalized populations into discussions related to core scientific concepts.

Vibranium as a Protagonist for Classroom Engagement

One approach is to use the fictional element of vibranium (Vb) (Figure 1) as a protagonist for classroom engagement. A narrative arc or structure (see Figure 2) illustrates an example of a Vb content story that can potentially be incorporated in a general chemistry course for first-year students. Inspired by a stoichiometry content story developed by Winston[13] and vibranium pedagogy developed by Collins and Appleby,[48,49] this content story begins with the key question—where does Vb fit on the periodic table? This illustration should be provided to the students for them to understand the connections between content beginning with the structure of atoms and the Bohr model. This also provides an opportunity for students to learn the history of both Mendeleev and Mosely regarding the development of the periodic table.[50]

Figure 1. Elemental symbol for the fictional Vb as used by d-Orbital Games.

In addition, student responses regarding the vibranium pedagogy assignment were extremely positive in the social science seminar course. One student shared after reading the vibranium article,[48] that the purpose of the article "is to get students interested in science by arguing where vibranium should be placed on the periodic table! In a way, it is sort of like tricking kids into learning chemistry because they are having a fun time doing it. Marvel speaks their "language," and it is a great way to get them excited about science."

Lesson plans and strategies to align these chemistry narratives about Brady, Ball, Greene, and Julian with chemistry concepts have recently been described by Collins[4,42] and other researchers.[37,38] Organic chemistry instructors can certainly have students design their own experiments focused on the synthesis of a carboxylic acid or ethyl ester following a CRE Model and screen the films focused on Brady (*Twenty Whites & One Other*) and Ball (*The Ball Method*) outside of class with their students. The Brady film is only 5 min in length and can be watched during class time. Another approach for organic chemistry instructors regarding ethyl ester concepts is to explore the substitution effects of aromatic ethyl esters with their students in the laboratory.[51] Furthermore, chemistry instructors could focus on medicinal chemistry to highlight the significance of Julian's contributions to society. A lesson plan or unit could include a collaboration with a history professor to discuss Julian's impact on Civil Rights. We recommend that the film celebrating Dr. Bettye Washington Greene's accomplishments be screened in class with students because it is 8 min in length. Greene's work focused on light scattering and polymer chemistry,[41−43] and her story could be shared when these topics are explored in the classroom with students.

Educators could also have students discuss the career trajectories and societal contributions of Brady, Ball, Julian, and Greene (see Table 2). Julian has a significant number of peer-reviewed publications and patents, followed by Greene, Brady, and Ball. This discussion of career trajectories provides marginalized students in STEM with the opportunity to begin defining and envisioning their own STEM futures beyond a college campus. There is a potential to then include conversations on navigating STEM careers in the face of U.S. societal issues such as discrimination in the workplace, identifying and/or developing safe work environments for marginalized communities, and self-agency related to the idea of protecting their intellectual property.[52]

CONCLUSION

Four narrative chemistry films celebrating the significant contributions of Brady, Ball, Julian, and Greene were screened in a social science seminar course based on three pillars of CRE with 13 students in the Spring 2022 semester. How should chemistry educators effectively incorporate specific narratives and apply them in course content? Through the power of storytelling, we demonstrated how chemistry educators can effectively incorporate specific narratives and apply them to course content. Our study suggests that these films had a positive impact on all students in the course as it relates to representation in STEM and the bridging of JDEI and STEM concepts. What perceptions do students draw from engaging in storytelling or watching documentaries in chemistry related courses? Examination of student reflections after watching the films may indicate an enhancement of the importance of JDEI within the STEM disciplines to create a sense of belonging for future generations of students of color interested in pursuing STEM. The responses also illustrate an understanding of

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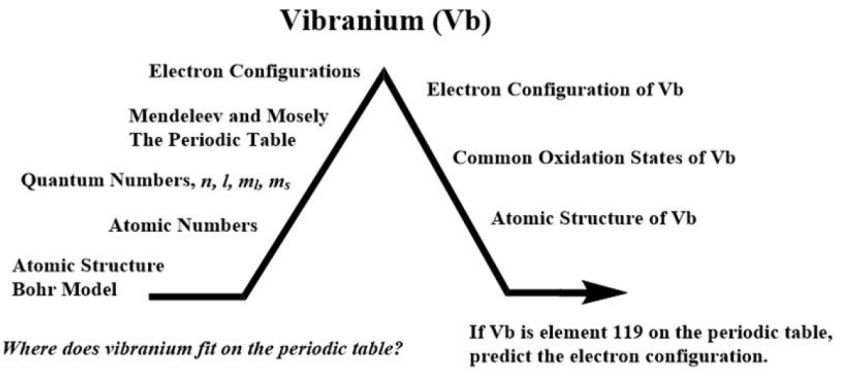

Figure 2. A narrative arc example for a vibranium chemistry content story.

Table 2. Career Comparisons of Brady, Ball, Julian, and Greene

Chemist	Dr. Saint Elmo Brady	Professor Alice A. Ball	Dr. Percy L. Julian	Dr. Bettye W. Greene
Research Expertise	Organic, Carboxylic Acids	Organic, Ethyl Esters, Medicinal Chemistry (Leprosy)	Organic, Steroid Chemistry, Medicinal Chemistry (Glaucoma, Arthritis)	Physical, Light Scattering, Latex and Polymer Chemistry
Employment Sector	Academia	Academia	Academia and Industry	Industry
Publications and/or Patents (SciFinder)	5	2	151	16

demonstrating empathy and sympathy toward others and finding solutions to address racism within our society.

Following Bell and Robert's STP Model, we identified Ball and Brady's stories as concealed stories, whereas Julian's journey in chemistry is a resistance story. Greene's journey in the chemistry community is an emerging and transformative story. Furthermore, we successfully created a counter-story-telling community within the social science seminar course. The students produced 12 new films focused on STEM topics, which could be considered as emerging and transformative stories. A key goal for the CRE-based projects is for students to become more effective communicators. Three students granted us permission to share their films on our *Storytelling in STEM Education* Web site,[53] which includes celebrating two-time Nobel Laureate, Marie Curie. Overall, we are pleased with the student projects.

Finally, the students were also provided an opportunity to share what they learned during the semester. One student wrote, "This class really helped me learn about under-represented scientists and how we as a society can help change things, so that history does not repeat itself. I think it also really helped me have deeper conversations about important topics, like equity." Thus, incorporating these historical narratives into the curriculum had a positive impact on the students in the course and demonstrated an enhancement in their understanding of the importance of JDEI in STEM fields. We also acknowledge that effective storytelling can be a strategy for students to share their STEM journeys beyond academia. This approach could be very useful for engagement with family and broader communities.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.3c00008.

Detailed information for the digital storytelling assignment and rubric criteria for students (PDF)

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Notes

The authors declare no competing financial interest.

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