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Integrating Race, Gender, and Indigenous Knowledge in the Introductory Physics Curriculum

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Introduction

The University of Detroit Mercy is a recent recipient of a National Institutes of Health (NIH) BUILD (Building Infrastructure Leading to Diversity) grant aimed at creating a career pipeline with the goal of increasing the participation of under-represented minorities (URM) in biomedical sciences research. Steep declines in the presence of these populations [1] within the biomedical research sector have caused sufficient alarm that the NIH has tasked grantee institutions "to implement and study innovative approaches to engaging and retaining students from diverse backgrounds in biomedical research, potentially helping them on the pathway to become future contributors to the NIH-funded research enterprise [2].

The goals of the BUILD grant dovetail well with intensive efforts within the physics community to transform and enhance the Introductory Physics for Life Sciences (IPLS) course sequence in ways that more fully integrate the foundational principles in physics with the education of biologists and life scientists. The introductory physics sequence remains a source of frustration for students of biology and the life sciences. A significant challenge that we face in our efforts to "engaging and retaining" students from diverse backgrounds is the lack of diversity and representation in science curricula, which too often present an image of scientific knowledge, accomplishments, and practice as the (almost) sole purview of White, European males, and some females.

That this has been a longstanding problem can be illustrated using a few examples. In a 1945 article published in the Journal of the National Medical Association, Dr. Joseph Williams, one of the leaders of the Beta Kappa Chi, the leading Black Scientific Honor Society in the U.S., warned of the challenges facing Black students of science. Though the language is somewhat outdated, I reproduce a lengthy and trenchant quote from the article [3].

> *Unfortunately for the Negro science major, the very subject in which he is interested has been formulated by Caucasians. It also appears as if all of the contributions on his subject were made by men of the white race. Contributions of the outstanding Negroes above have been lost in the maze of literature which is predominantly by white men. The Negro science major, however, must read his textbooks, books borrowed from either white or Negro libraries and pure science journals. Generally, he can find nothing in these that he can point to with pride as a contribution by a Negro. Consequently sophomores, juniors and seniors question their chances for making their contributions in science to society.*

The second example comes from a recent study of introductory physics textbooks, in which the authors found that "the distribution of images in 11 physics textbooks" over a period of 56 years, from 1960-2016, showed that "[w]omen and ethnic or racial minorities are still underrepresented in physics at nearly every level of education and academia" [4]. In recent years, the demographic and curricular under-representation of women and racial minorities has led to increased attention to equity and social justice issues in STEM in an effort to "change the culture of science to be more welcoming and inclusive" [5]-[7]. In the wake of George Floyd's murder and the racial justice protests that followed, many national organizations issued Black Lives Matter statements and pledged to redouble their efforts to address the racialized history and impact of science [8], [9]. These statements expressed similar sentiments and commitments to "increasing the participation, inclusion, and empowerment of historically underrepresented segments of society in all venues where [science and engineering] is taught, practiced, and supported." One approach to fulfilling these commitments is the notion of "decolonizing" the STEM curriculum [10]. Such an approach does not seek to "reject established fundamental knowledge" because it is part of a historical trend that includes European colonialism and racism. Rather, the focus is on a critical engagement with curricula, looking at "potentially different approaches to the way this knowledge is produced or applied" with the goal of improving educational outcomes and student participation.

These examples illustrate the two main questions this paper addresses: how do we build more inclusive curricular content in introductory physics courses to (1) discuss issues of race, ethnicity, culture, and equity in science, and (2) broaden the social and cultural contexts in which physics knowledge is created, and utilized? The larger context of these efforts is an exploration of "*how social issues and values affect the way we understand (and practice) physics and its relation to life?*[11]*"*

In this paper, I will discuss two multi-week course projects that required introductory physics students to read historical biographies and respond to the scientific and social issues in the story. In the first semester of a year-long course, students were required to read Margot Shetterly's *Hidden Figures: The American Dream and the Untold Story of the Black Women Mathematicians Who Helped Win the Space Race* [12]. The central narrative of race and gender in NASA's history is interspersed with descriptions of rocket propulsion, Newtonian forces, momentum conservation and other topics prevalent in introductory physics. The second semester biography was *The Boy Who Harnessed the Wind*, by William Kamkwamba and Bryan Mealer [13]. Kamkwamba's personal story of his innovative construction of a windmill in his native Malawi is suffused with introductory physics concepts – energy, electromagnetism, thermodynamics, and fluid flow.

In the next section, I briefly outline the pedagogical frameworks undergirding this project. In the following two sections, I discuss each project, in turn, providing examples of assignments that integrated the curricular content of introductory physics with socio-cultural issues are presented in the next section. The penultimate section presents the results of surveys that gauged student attitudes and responses to the assignments and the overall project. Finally, I conclude by identifying some challenges and opportunities presented by the project to the effort to build a more inclusive physics curriculum.

Pedagogical Frameworks

Exploring the two questions posed by this paper in the context of the course projects required three different, but inter-related pedagogical frameworks. The first framework addresses the incorporation of race and equity issues in physics through an initiative called *The Underrepresentation Curriculum Project (URC)*. The project website identifies it as "A flexible curriculum designed to help students critically examine scientific fields and take action for equity, inclusion and justice [14]. In a handout, they explain the significance of studying cultural issues in physics as follows [15]:

> *Why in a physics class, though? Because learning about the culture of a field is learning about the field and because these are ideas that cross disciplines. Whether or not you go on to study physics, having an understanding of how people end up doing what they do (and, more broadly, how our society functions) is a critical aspect of learning and thinking critically. In other words: why not a physics class?*

The framework begins by interrogating the flawed assumption that the "objective" nature of physics knowledge is independent of the cultural context in which physics is practiced, thereby questioning the "myth that science is an impersonal affair, divorced from human concerns." Questions about subjectivity lead naturally to questions about "*who does physics, who doesn't, and under what conditions*." This question formed the basis for the assignments created as part of my course.

There are many ways to learn about the culture of a field and physics is no different. Popular approaches to introducing diversity issues in the physics curricula include highlighting the work and lives of female physicists and physicists of color [16]; creating separate units that focus on equity issues and the "nature of physics [17]; and others. A weakness of these approaches is that they are frequently divorced from the traditional content of introductory physics, whose learning outcomes are justifiably dictated by the graduate programs and professional organizations of the students' major disciplines [18]. This project seeks to remedy this deficiency by using a storytelling framework [19] that highlights sociocultural issues in physics within the explicit context of introductory physics concepts, such as kinematics, Newtons' laws, conservation of energy and momentum, and electromagnetism, to name a few. The narrative framework of storytelling used in these projects contrasted with the traditional framework of "logical-scientific communication" used in science courses. While latter seeks to present universal, generalized, widely accepted truths, the former emphasizes specific, contextual experiences. A well-chosen narrative can not only induce an understanding of the general truths embodied within a personalized story, but as [19] elaborates, it can do so in a way that communicates science to non-experts through an efficient, engaging and persuasive method.

The benefits to students of any pedagogical approaches to curricular material must always be a concern for educators. It is important to ensure that students receive the benefit of "effective educational practices [20]." The framework of "High-Impact Educational Practices" (HIPs) has been shown, through extensive research, to produce significant educational benefits to all students, including traditionally underrepresented students in higher education. More details about HIPs can be found, for example, in [20]. Three of these practices were relevant to this project and integrated into the assignments: (1) *Diversity and Global Learning*, aimed at exposing students to different worldviews and cultural issues in the context of sensitive issues, such as race, gender and human rights; (2) *Collaborative Assignments and Projects*, which emphasizes collective discussions and team-based assignments; and, (3) *Intensive Writing*, which requires students to produce and reflect upon, not only what they write as part of an assignment, but to also respond to the writings of others by interrogating the nature of, and the audience for whom the writing was intended.

Employing these frameworks and the practices embedded within them proved to be a significant but enjoyable, ongoing challenge. That these biographical histories are centered on race, gender, ethnicity, and other socioeconomic issues is clear. In addition, their interdisciplinary and global nature met the requirements of the pedagogical frameworks used. As part of the assignments, students were also required to read separate articles and primary source material of a historical, philosophical, or newsworthy nature on issues as varied as racism, climate change, deforestation, poverty and famine, the Cold War, and the Space Race. Students worked in pairs on some of the physics-based assignments, engaged in online discussions on the sociocultural questions, and completed short essay assignments, as the examples in the next two sections illustrate.

Hidden Figures Assignment Examples

The back cover of the book, Hidden Figures, describes the "phenomenal true story of the black female mathematicians at NASA whose calculations helped fuel some of America's greatest achievements in space [12]. The description includes this excerpt:

> *"Even as Virginia's Jim Crow laws required them to be segregated from their white counterparts, the women of Langley's all-black "West Computing" group helped America achieve one of the things it desired most: a decisive victory over*

> *the Soviet Union in the Cold War, and complete domination of the heavens."*

Students were asked to focus on the following thematic questions [21]:

- What were the paths that brought these remarkable women to Math and Physics and their accomplishments at NASA? How were these paths influenced *positively* by the political, social, and cultural environment of their families, communities, culture, and nation?
- What obstacles did they have to overcome in their personal quest for mathematical and scientific knowledge, and their dreams and desires to contribute to their country? How were these paths influenced *negatively* by the political, social, and cultural environment of their families, communities, culture, and nation?
- What points of connection, and points of separation, do you find when you compare *your journey in science education* to the journey of these women and those with whom they worked?

Early in the book, the author describes an instance of the segregation rules, or "lunchroom hierarchy" that was enforced in the cafeteria of the NACA center in Langley, Virginia. The all-Black West computing group of women were forced to sit at a table specifically marked for "colored computers". Students were asked to write a short essay on an online course Discussion Forum on the following question:

> *Question: What is the "lunchroom hierarchy" that the author talks about on Page 42 and beyond? Does this "lunchroom hierarchy" established in the NACA cafeteria violate the "prohibition of discrimination" language in E. O. 8802 or not? Whether you answer "YES" or "NO, discuss what language in 8802 backs up your reasoning?*

E.O. 8802 refers to President Franklin Delano Roosevelt's Executive Order 8802: *Prohibition of Discrimination in the Defense Industry*, in June 1941 [22]. Students were provided a link to an image of the original document at the U.S. National Archives where they were able to read that Roosevelt had ordered "that there shall be no discrimination in the employment of workers in defense industries or government because of . . . race, creed, color, or national origin". That these Black, female, mathematicians and scientists were engaged in seminal and groundbreaking analyses on the aerodynamics of WWII military, while being subjected to constant racial insults, was clear to the students. The assignment engaged their ability to think critically about the interplay between these ideas. I excerpt a couple of student responses below:

> *"When they were hired, there was no doubt that those women were intelligent enough to perform the job and understand all the math, but ironically, they were still discriminated against and looked at completely different when time came to the simplest human act of eating."*

“The sign in the cafeteria was evidence that the law that paved the way for the West Computers to work at Langley was not allowed to compete with the state laws that kept them in their separate place and was mentioned in the book to show that… the state laws of keeping workers of different races separate was still relevant.”

One of the key airplane design contributions made by NACA workers, including the Hidden Figures, was the creation of laminar, aerodynamically superior wing shapes, a factor that “contributed to [the] superior performance” of the P-51 Mustang. The Mustang was a long-range, single-engine, propeller-driven fighter-bomber used during World War II, which became the signature aircraft of the all-Black squadron famously known as the Tuskegee Airmen [23]. Students were provided links to learn more about the history and accomplishments of these famous fighter pilots. They were assigned a worksheet that used the specifications [24] of the P-51 Mustang fighter plane to study some of the forces involved when planes climb through the air, either during takeoff or during flight maneuvers. They were required to complete the following steps, based on the free-body diagram below, which was provided to them:

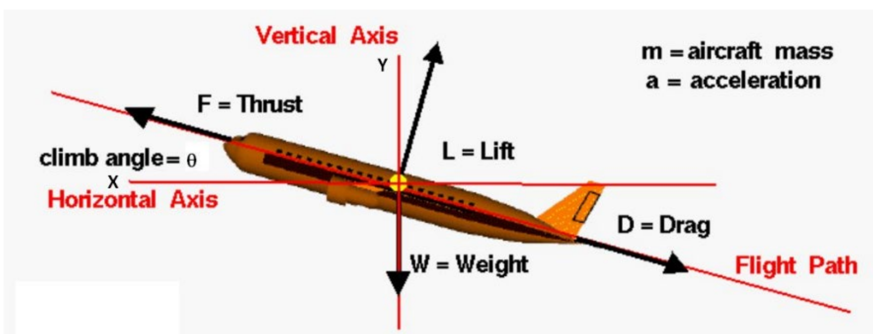

Figure 1. Forces in a Climb on an Airplane [25]

- Use the mass of the plane to calculate the weight force, W.
- Use the engine power specifications to calculate the thrust force, T, on the airplane.
- Use the lift-to-drag force ratios to calculate the lift force, L, for a given drag force, D.
- Using the free-body diagram and applying Newton’s 2^{nd} law, calculate the vertical and horizontal accelerations of the Mustang during take-off.

The physics assignments were not designed to be arduous or very challenging. Rather, the goal was to the satisfy one or more course learning outcomes (“Apply Newton’s Laws to analyze and predict the motion of objects”) within the context of the narrative in the chapters they were assigned to read.

The Boy Who Harnessed the Wind Assignment Examples

I had students in my second semester class read the book, *The Boy Who Harnessed the Wind: Creating Currents of Electricity and Hope*, by William Kamkwamba and Bryan Mealer, a remarkable story of an amazing young scientist and inventor from Malawi. Kamkwamba's personal story of his innovative construction of a windmill is suffused with introductory physics concepts embedded in an intense social context of poverty, famine, deforestation, and climate change in his native Malawi. Excerpts from the publisher's summary [26] of the book illustrates these connections:

> *"William Kamkwamba was born in Malawi…a land withered by drought and hunger. With a small pile of once-forgotten science textbooks; some scrap metal, tractor parts, and bicycle halves; and an armory of curiosity and determination, he embarked on a daring plan to forge an unlikely contraption and small miracle that would change the lives around him."*

Students were asked to focus on the following thematic questions [21]:

- What was the path that brought William Kamkwamba to physics and the invention of his windmills? How was this path influenced *positively* by the political, social and cultural environment of his family, community, tribal ancestry and culture, and nation?
- What obstacles did he have to overcome in his personal quest for scientific knowledge and innovation? How was this path influenced *negatively* by the political, social and cultural environment of his family, community, tribal ancestry and culture, and nation?
- What points of connection, and points of separation, do you find when you compare *your journey in science education* to William Kamkwamba's journey?

As we learn from the book, the rapid growth in the tobacco industry is responsible for the deforestation in much of Malawi. In turn, Kamkwamba explains, deforestation has caused soil erosion, environmental degradation, crop shortages, and a fuel crisis, all described with deep emotion and feeling by the author. William Kamkwamba's experience of poverty and deprivation in Malawi was far from unique. Most of his friends could not afford to go to school; most families in his town struggled to put food on the table, or even survive! Students recognized that William's achievements and his perseverance with his windmill project, in the face of these immense challenges, was all that more amazing and empowering! Yet, they also learned that his family's "half-acre of tobacco" was a "lifesaver" during the worst periods of deprivation, and that he garnered the parts for his windmill from a tobacco plantation scrapyard. Students learned about the environmental and health impacts of tobacco through a Bulletin of the World Health Organization [27]. They contrasted this with William's economic and cultural encounters with tobacco farming, and considered the complicated role of tobacco farming as a systemic explanation of the overall situation of Malawians:

Question: How do you see the role of tobacco farming in William Kamkwamba's life and in the struggles of ordinary Malawians?

An earlier assignment challenged students to think differently about indigenous knowledge systems. Partly, this was prompted by an ill-informed, Eurocentric description of Malawi as "a country where magic ruled and modern science was mystery." Absent a cultural context, magic becomes a symbol of a superstitious mysticism, inferior, irrational, and backward, without a future, a primary determinant of the dire circumstances of Kamkwamba's Chewan community. Science historians and anthropologists recognize that often, in societies with ancient knowledge systems, "what is holy to indigenous people can be kept alive, unsuspected inside a story, though told over and over, remaining disguised inside an ancient sacred metaphor [28]." Students were asked to read an article [29] that contrasted western science with indigenous science; to compare a system that favors "reductionist, mechanistic and quantitative methods with one that observes 'natural phenomena from a global point of view" and gleans "observations [that] are strictly linked to local culture and to the predominant philosophy." The author provided a lengthy quote from Nobel Prize winning biochemist, Albert Szent-Gyorgyi, to illustrate his point. Students were then asked to write a short essay on the following questions:

Question 1: What is the author's intent in reproducing this quote? What point is he trying to make? How does he use this quote to contrast western science and traditional knowledge?

Question 2: What are your thoughts about the influence that magic had on William's early childhood? Can you think of a favorite example from your own childhood that had a significant influence on your life?

Student responses to the second question were quite unusual and fascinating. Many recognized that magic piqued William's interest in science and noticing that this was also true in their own lives:

"Magic could no longer answer his questions about the world around him, so he had to look elsewhere for the answers. This lead [sic] him to science because it could explain how things like wind and energy worked."

"Fairy tales have played a significant role in my life… when I was a child I always wanted to look for mermaids in any body of water. I always wanted to find just one mermaid, which sparked my interest in learning more about the ocean."

"For my life, I felt a moment which significantly impacted me was my first time playing computer games. Not only had it sparked an interest in technology but it

also made me interested specifically in computers."

The physics assignment was an attempt to reproduce the electrodynamics of one of Kamkwamba's windmill designs. Wind power is converted to electricity through a bicycle dynamo in contact with the rim of a wheel attached to the axis of the rotating blades. Students were asked to calculate the peak voltage generated by the dynamo and compare that with the description that Kamkwamba provided in chapter 11 of the book. They were then required to write a short essay on how William designed a homemade transformer using scrap parts and used it to convert this voltage into a higher AC voltage to power a phone charger. The steps in the problem were as follows:

- Use typical summer wind speeds in Malawi, to calculate the angular velocity of the windmill
- Use this value to calculate the angular velocity of the bicycle dynamo
- Use the angular velocity and other values for a typical dynamo to calculate the peak voltage generated by the dynamo

Students, working in pairs, were able to apply the knowledge of rotational motion, magnetic induction, generators, and transformers that they had learned in course topics on electromagnetic induction to complete the calculations. They were pleased to obtain values close to those described in the story.

Another physics assignment asked students to explain the energy transfers and energy transformations in windmills. They integrated the concepts of energy, fluid flow, and electrical efficiency of wind turbines to estimate the electrical power output of Kamkwamba's windmill. Once again, they obtained results that mirrored the actual description in the story. While both assignments can be improved in terms of learning outcomes and challenging the students to research and gather more real-world data to solve these problems, the focus is intended to show the connection between the physics they study and the role it plays in people's lives.

Student Responses to the Projects

In each semester, students completed anonymous pre and post surveys of their general knowledge on the topics discussed in each book, as well as their attitudes towards the incorporation of race, gender, and other sociocultural issues in physics. Particularly, students were asked to respond to (1) their sense of the importance of discussing social issues in the classroom, and (2) their sense of the importance of diversity issues in physics.

Table 1 below lists students' responses to some of the Likert-scale questions in the survey from the project on *The Boy Who Harnessed the Wind*. Chronologically, this project was first introduced into the course in the Winter 2020-21 term. The total number of completed surveys was N=47, out of a possible 48 students in the class. There were thirty questions in the survey.

Thirteen questions were related to social issues and belonging in Physics and were adapted from The Underrepresentation Curriculum pre-post survey [14].**Error! Bookmark not defined.** The wording shown in bold in a couple of questions reflects the language used in the post-project version of the survey.

Survey Question	**Strongly Agree or Agree**		**Strongly Disagree or Disagree**	
	Pre-Survey	**Post-Survey**	**Pre-Survey**	**Post-Survey**
I am excited/(**I was happy**) to read the book *The Boy Who Harnessed the Wind* and learn more about how physics and social values are related to people's lives.	60.8%	71.2%	15.6%	11.5%
It is/(**was**) important for this Physics class to talk about social issues to help see their connection to Physics and to help solve society's problems.	51.0%	73.1%	19.6%	9.6%
It is important to learn about diversity in physics**.**	68.6%	78.9%	7.9%	7.6%
I have a responsibility to take action to promote diversity in physics.	51.0%	65.3%	13.7%	9.6%

Table 1. Sample of Pre and Post-Project Likert-Scale Questions on Social Issues and Diversity in Physics

Student responses to the Hidden Figures project in the Fall 2021-22 term were quite similar. Unfortunately, despite being in-person, the semester witnessed more significant COVID-19 disruptions, which affected the number of students who completed the post-project survey. Nevertheless, the overall results were as positive as those shown in Table 1. As one example, 65.1% of the students in the pre-project survey, and 74.1% in the post-survey, strongly agreed/agreed that they had “a responsibility to take action to promote diversity in physics.”

Students in both cohorts were asked for their individual responses to the question, "What was something important you learned from reading the book, <title>, and completing the assignments?" It is interesting to note that of the total student responses in both courses (N = 88), only two students responded negatively this question. Table 2 below provides some illuminating excerpts from responses to the query for the project on *The Boy Who Harnessed the Wind*.

Student 1	*I think the most important thing I learned while reading the book was to not take my education for granted… I think I am a better student and a better person for that.*
Student 2	*I learned about how someone can use physics to change their lives, and that physics can be so inspiring!! P.S. I absolutely LOVED the way that the recitation assignments were based on the book.*
Student 3	*I loved reading this book and I definitely think you should continue to incorporate this text into your future courses. It was a fun read but also made us think critically. I had not known about this book prior to this class!*
Student 4	*One of the parts that stuck out to me the most was the complicated relationship the Malawians had with the tobacco fields. They were having issues with the fields because they were harming their environment while also taking up field space where they could grow sustainable crops, but they needed those fields in order to survive.*

Table 2. Examples of individual student responses to the question "What was something important you learned from reading the book and completing the assignments?"

Table 3 includes example responses to the same question from the *Hidden Figures* project.

Student 1	*I really enjoyed how this book combined social issues with race, gender, the work force, social life (home and society, such as neighborhood) and its based on a true story. The reader can have more understanding and knowledge from reading from the perspective of the women in this book and how the battled through the barriers they had.*
Student 2	*It was refreshing to read a book that truthfully revealed in (mostly) positive light the stories of hardworking women who made American space travel what it is today…I read it seeking physics topics covered in class but also viewing the complexity that is having representation in these fields.*

Student 3	*Reading Hidden Figures was delightful and allowed me the opportunity to further reflect on the role Blacks can play in the advancements of our country. I've grown accustomed to it but when I sit back and think about, I've realized I've never had many minority professors in my school journey...Stories like Hidden Figures are so important to share because it shows that changes can be made with enough persistence and time. It was a very encouraging read and should be recommended for future classes.*
Student 4	*I really enjoyed learning the history about these women, especially Katherine Johnson. So, I am very appreciative that it was assigned…I find it empowering that John Glen (sic) wanted the final stamp of approval to be from Katherine Johnson, that is a testament to her intelligence and showed that race and gender have no bearing on an individual's ability.*

Table 3. Examples of individual student responses to the question "What was something important you learned from reading the book and completing the assignments?"

Conclusion

In this paper, I have presented a specific model for introducing sociocultural issues in an introductory physics course, through using biographies and real-life stories that highlight issues of equity and social justice. Rather than creating a narrative to accompany assignments in physics, as is sometimes done using context-rich problems [30], these projects created physics assignments and sociocultural reflections to accompany narratives that centered issues of race, gender, socioeconomic status, environmental issues, and indigenous knowledge systems. As student responses indicate, they found these projects to be very empowering and illuminating, enhancing their interest in introductory physics, and piquing their interest in the role that historical and cultural factors play in the production and use of scientific knowledge.

Finally, it is worthwhile mentioning two challenges in the implementation of this model: one, there is a relative lack of biographies and historical narratives involving social justice and equity issues that include significant physics content at an introductory level; two, getting students to read books remains a persistent problem. This latter problem was partially mitigated in my courses by making these projects a small but significant part of the course grade. Most students in these courses are undergraduate life-science majors who are highly motivated to do well in order to enhance their chances of gaining admission to medical or dental schools.

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