Spring 2022

Inquiry-Based Astronomy Curriculum for the Online Setting that is Culturally Sustaining and Equity-Centered

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by

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A capstone project submitted in partial fulfillment of the requirements of Master of Arts in Education: Natural Science and Environmental Education

Hamline University

St. Paul, Minnesota

May 2022

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TABLE OF CONTENTS

CHAPTER ONE

Introduction

Science is synonymous with inquiry, so it follows that effective science lessons are built around asking questions and allowing students to work towards solutions. As child psychologist Piaget outlined, learning is most impactful when students explore and make their own meaning: connecting the familiar to the new. If a student shares that science is their favorite course, most of the time the reason given is "the experiments".

Using an inquiry-based approach is vital to both student engagement and teaching critical thinking and problem solving, essential skills in our ever evolving 21st century landscape. The digital age has made information readily available, decreasing the importance of knowing facts—which can be quickly googled. Instead, it is the application of knowledge and development of skills that gains a new importance.

As vital as hands-on activities are to science, there are various barriers to ensuring that each student has access to this type of engaging science education. In the best of times, funding discrepancies lead to stark differences between the facilities of well-off districts and those where teachers are providing laboratory supplies out of their own pockets. The onset of Covid-19 instilled a universal barrier to implementing experiments when all districts were forced into distance learning or a hybrid model to cope with the pandemic. Given the continued uncertainty of the safety of in-person learning, distance learning remains an integral option for families and students, especially those with health concerns. The prevalence of distance learning means that teachers need to find ways to design engaging curriculum in this setting. This leads to my research question: *How can*

inquiry-based astronomy curriculum that is culturally sustaining and differentiated be effectively adapted to the online setting with student equity as a prime consideration? In this chapter I will emphasize the importance of incorporating inquiry into science lessons by sharing my own experience with science education. I will then identify some of the benefits of distance learning and describe what led me to teaching science in the online setting. I will highlight recent events that have resulted in distance learning being implemented on an unprecedented scale. Next, I will identify some of the challenges embedded into adapting inquiry-based science lessons to distance learning. Finally, I will discuss what led to selecting astronomy as a template for designing engaging, culturally sustaining lessons in the online setting.

Background with Science Education

I never planned on being a science teacher. My path towards education was a circuitous one, and even once I considered teaching, science was not the subject that initially came to mind. This lack of interest was invariably influenced by my own experiences with the subject. It is not that I did not like science or do well in it; I was the type of student who would revise my work to get my score from a 96% to a 98%. Rather, it was that science class lacked luster in comparison to other courses.

Growing up, I attended a small school in rural Minnesota. From preschool to 12th grade there were about 150 students in total. The science room at our school was the one classroom with a sink. While our teacher did her best to make the class interesting, experiments and inquiry-based activities were limited, both by a lack of funding and teacher time. In this small school my science teacher taught all science courses from

seventh to twelfth grade. Class consisted of worksheets and answering questions from the textbook. How was this supposed to compete with math where we were actively solving problems or Spanish where we were learning how to communicate with people from around the world? Sure, science provided a collection of facts which was enjoyable enough, but what was the point of it? A seeming lack of application left me wondering how relevant the subject was.

While my exposure to laboratory exercises was limited, I vividly remember the few experiments we did have. In chemistry, we had to separate an unknown substance into its component parts using our knowledge of physical versus chemical properties. While it was vexing at first, it was also exciting to collaborate with classmates and test out different hypotheses. Experiencing failure and having to come up with new approaches gave me an appreciation for the true nature of science that could not be gleaned from a textbook.

It was not until college that I took courses that piqued my interest in science. As a PSEO student—or Post Secondary Enrollment Option where high school students have the opportunity to complete college courses—I took an environmental science course at the local community college. It was taught by Professor Wold, who had a sense of humor so dry that when he told a joke, most students looked from him to their notes, wondering if it was something they should write down for the test. Professor Wold's course was the first truly engaging science course that I completed. Whenever possible, he used local examples that helped us to realize the abstract ecological principles under investigation

were taking place right in our backyards. The course helped bridge the gap between the facts I enjoyed collecting to real-world applications.

While I had enjoyed a science class for the first time, my passion was in studying languages, so when I graduated, I initially attended the University of Minnesota, where I planned to major in Chinese and participated in the AFROTC program, or the Air Force Reserve Officers' Training Corps. My plan had been to join the Air Force after participating in the program, but then a string of physical injuries led me to change my major to biology in the hopes of becoming a physical therapist.

Tragically, someone had decided that chemistry was an important component to biology, so I enrolled in chemistry where the lectures were fantastic, but the labs felt like Potions class in a Harry Potter book: the Teaching Assistants would give you various jars of white powder, unfamiliar equipment, and a seemingly impossible end goal. There was no lab book, no steps to follow, just Teaching Assistants instructed to remove the guidance from the Zone of Proximal Development and instead provide lots of encouragement and the helpful, "Come on, you guys know this" when we, in fact, would not. Eventually, a Teaching Assistant would see the sad desolation in our eyes as we contemplated what we would change our majors to after we failed General Chemistry and provide enough instruction for us to stumble through the lab. Suffice to say, the experience was survived rather than enjoyed. But it did leave me with the strong impression that having access to a laboratory was not synonymous with inquiry-based learning. Instruction has to be scaffolded to meet students' needs, regardless of setting.

The next year I transferred to Bethel University in search of smaller class sizes. Fortunately, here I continued to take science courses that made me fall further in love with the subject by working with actual live mice or venturing outside to observe how invasive species were transforming our local ecosystem. The classes were impactful enough that when my volunteer tutoring experience at an afterschool program led to a desire to enter education, teaching biology felt like a natural step.

Entering the Digital World

I completed my degree in Life Science Education, but I still had apprehension about entering the world of education. My practicums and student teaching experience had varied from magical—such as getting to teach in England—to harrowing. My student teaching experience was challenging. I taught in a Twin Cities school with a high degree of poverty under a teacher mentor that was so burnt out he quit in the middle of the semester. While I had enjoyed working with the other faculty and most of the students, I was not eager to take on having my own classroom. I was apprehensive of repeating the experience in a new setting, with time devoted to managing student behavior rather than delving into science concepts.

As I was having this crisis of career planning, my younger sister was graduating high school after earning her diploma from an online school. She loved the flexibility it provided, enabling her to complete her classes around her work schedule and work through the lessons at her own pace. Perhaps teaching online could help to resolve my tension between wanting to teach but not wanting to have to spend so much time on classroom management?

I was not a stranger to distance learning myself. As a PSEO student, I had taken multiple fully online or blended courses. It ranged from world history with filmed lectures to physical education, the most natural of courses for the online setting. Fortunately, rather than having to do jumping jacks via Skype, the course took an adapted approach of submitting an activities tracking sheet. Amidst the early exposure to online education, there had even been a science course.

During my senior year of high school, I was taking PSEO courses full time and was ambitiously splitting my schedule between the local community college in Cambridge and the University of Minnesota. I registered for the online version of a biology course partly for the flexibility to make the schedule work, but also because this experience predated my appreciation for the importance of laboratory components. In fact, while I enjoyed the professor's online lecture, I did not know what to make of the experimental portion at first. I picked up a light, but cumbersome box of supplies for the experiments that I would conduct mostly at home. It was too large to carry between classes all day, so it would have to be stored somewhere. As I pressed on the edges enough that the Biology Box could be crammed into my locker at the school's fitness center, I prayed that labs would not be a repeat of potions class.

Once I returned home, I opened the box to inspect its contents: seeds, magnifying glasses, pipettes, etc. At first, the items seemed disparate in purpose. But the instructors for the distance course did an excellent job of providing directions and rationale for each activity. Gradually, each item fell into place as a necessary component for surprisingly enjoyable at-home experiments. I looked at aerobic versus anaerobic respiration through

growing plants and making kimchi. No extra credit was awarded for the mold cultivated in the early attempts. In contrast to the chemistry labs that had felt disconnected from the concepts in lecture, the at-home biology experiments felt like a natural extension of previous learning. With the right supports, experiments were possible in a range of settings. I decided to give teaching science online a chance.

Teaching Online

As I started teaching at a fully virtual K-12 school, I discovered teaching online, especially science, has its own challenges. While the school I teach at is based in St. Paul, it has students from all over the state, from urban to rural locations. It is an incredibly diverse demographic with very disparate resources and settings. How could I design hands-on activities that provided meaningful experiences that engaged students, especially when students have such varying resources and support? While I am currently in my fifth year of teaching in the online setting, I am still striving to answer the question: *How can inquiry-based astronomy curriculum that is culturally sustaining and differentiated be effectively adapted to the online setting with student equity as a prime consideration?*

When students are in school they all have access to the same resources within a particular setting. In online learning, each students' learning space and access to resources is highly varied. Some students have a parent who is home during the day to help guide them through the lessons. Other students are home alone and tasked with watching their younger siblings. Some have reliable high-speed internet while others have an unreliable internet connection and need to share their computer with another

sibling. These general disparities do not even address the differences in materials available for experiments and access to the outdoors, hugely important factors when teaching an engaging science course.

For some, physical experiments and outside exploration are a must for engaging science lessons. For others with financial or physical limitations, having an online alternative is essential. When providing differentiated instruction to meet students' learning needs, online teachers must account for a wide range of variables.

Living in Unprecedented Times

In March of 2020, distance learning transitioned from an option chosen by a few to a requirement for almost all. The lack of information and rapid transmission of the novel coronavirus meant that schools across the country were abruptly transitioning to a distance or hybrid model. On extremely short notice, teachers had to adapt their in-person courses to the virtual setting. Suddenly, questions on how to teach effectively online became a pressing concern for schools across the country.

While distance learning is relatively new to most schools, it has been around longer than most realize. The online school at which I currently teach started in 2005 with only a handful of teachers and students and steadily grew to about 2500 students in 2019. Even before the pandemic, there were many students that actively selected online learning as an alternative to in-person learning.

There are a variety of factors that bring students to distance learning. For some, it is the flexibility to pursue professional sports or accommodate a work schedule, but for many, they are attracted to distance learning for the same reason I was: having a safe

place to focus on learning. Many of our students have IEPs—Individual Education Plans which are documents that define the supports that need to be provided to students enrolled in the special education program—and come to the online setting to be able to work in an environment with less distractions that enables working one-on-one with teachers more easily. Another reason for coming to the online setting was escaping bullying that took place while they attended brick and mortar school. Even before the pandemic, there were students that relied on distance learning as a safe place to learn.

Nearly a year and a half since the onset of the pandemic, the safety of in-person education is still in question, necessitating the continuation of distance and hybrid education on a large scale, making questions regarding effectively adapting science to the online setting even more paramount: How can inquiry-based practices be implemented when the instructor and learners are potentially separated by great distances? What kinds of mental frames need to be developed to help students be curious investigators of their local world and effective communicators of this information with their fellow learners? If leveraged correctly, I believe that embracing observations made during distance learning can enhance students' understanding of the natural world by enabling them to both recognize patterns across settings while also investigating what makes their location unique.

Why Astronomy?

For many, astronomy is not the first discipline that comes to mind when they think of science, much less inquiry. When most imagine investigating a hypothesis, they envision beakers, white coats, and, well, you can see where I am going with this. The

misconception of science investigations occurring solely within sterile labs is affirmed by a quick image search of “science lab”. But of course, science is much broader than the confines of the laboratory.

One reason I am designing curriculum for astronomy is its ubiquitous nature; I want to help students see that learning is not about earning a grade but about understanding the world around them. It is not a process that starts and ends with a bell, but a life-long endeavor. Students may enter a variety of fields, but each has access to the night sky in some form or another.

In a traditional educational capacity, astronomy is an elective course in high school, but concepts from astronomy are covered as early as third grade, again in sixth grade, and then within Earth and Space Science in ninth grade (MDE, 2021). This year, I am teaching two high school astronomy electives in the online setting. The curriculum is premade by Pearson Education, and in all honesty, the courses are subpar. The lessons simply give students slides of information to read and then questions to answer--usually multiple choice. There is no inquiry, no engagement. Tragically, this is not an isolated incident. During my student teaching, my teacher mentor would talk over a powerpoint on the astronomy concepts students needed to know and then give them a worksheet to assess comprehension. It was heart wrenching, then and now, to see students view astronomy as distant and esoteric, especially when astronomy has so much potential to engage learners of all backgrounds.

Opportunities for Inclusion

As mentioned, my degree is in biology education. Yet, I also possess a middle school science license, which I procured mostly so that I could teach astronomy at this level. This year, I am also teaching both astronomy and physics for the first time at the high school level.

I have always loved astronomy, and my affection for it has only grown with time. Like most sciences, astronomy is paradoxically ubiquitous and yet elusive until the learner possesses the knowledge to make sense of their observations. I grew up in a small town with minimal light pollution which afforded an excellent view of the night sky. When I was younger, I found the vast expanse stunning but overwhelming. There was just so much to see; how were you supposed to keep track of it all? Then I gradually learned the constellations and a few of the prominent star names. Ursa major and minor, perhaps, better known for their asterisms--or collections of stars within a constellation--the Big and Little Dipper quickly became my favorite. I was fascinated by the fact that Dubhe and Merak--stars of the Big Dipper--always pointed to Polaris, the current circumpolar north star, even as they rotated through the night sky. Like the other sciences, recognizing the one small pattern helped me to make order out of what had seemed like chaos.

I find constellations--or patterns of stars and the regions around them-- incredible. Not only do they help us organize and catalog thousands of stars, but they also teach us a great deal about humanity in the process. When I took astronomy, I learned the Greek and Roman names along with their myths that they connected to the movement of the stars.

Learning about how they had interpreted the objects in the sky provided insight into their language, history, and culture. It was not until this year when I started teaching astronomy at the high school level that I realized the wealth of learning opportunities that astronomy and its constellations provide.

In an effort to increase the inclusivity of our curriculum, a history teacher at our school asked us teachers to look through our courses and reflect on the representation of other cultures present, specifically native groups such as the Dakota and Ojibwe. As I looked through the premade lessons provided by Pearson Education, I was perturbed to discover that it was devoid of representation of any kind. Looking through the lessons on the history of astronomy, I found that they briefly acknowledged the base-60 counting system of the Sumerians before going in depth into the Greeks and Romans and then jumping to the European scientists involved in the Copernican Revolution.

I realized that the astronomy curriculum--also like most of the sciences--is incredibly Western centric. Humans have been studying and making meaning of the stars for millennia, and many--such as the Chinese--have kept accurate records of celestial objects that aid astronomers to this day (History of Astronomy in China, n.d.). And yet, when I examined my curriculum, the contributions of other cultures have been entirely overlooked. Numerous high school Minnesota Earth science standards emphasize the importance of including Indigenous knowledge (MDE, 2021), and astronomy is a natural window into this world.

Furthermore, astronomy provides opportunities to investigate hosts of other cultures whose contributions have gone unacknowledged for far too long. When I took

astronomy at college, I learned that two-thirds of the stars have Arabic names (Odeh, 2021; Tyson, 2020), but I did not pause to consider the significance of this fact. It took encountering an error in the curriculum I am working with to investigate the contributions of Arabic scholars. The lesson stated: "The Greeks and Romans were the first to name the constellations" (Pearson, 2020), which took me back since it was patently false. Yes, the 88 officially recognized constellations have Latin names (Smale, 2018) and most were recorded by the Alexandrian (Greek) astronomer Ptolemy in 140 CE (Engelbert & Dupuis, 2003). However, Ptolmey was hardly the first to name or associate stories with patterns of stars, and there was over a thousand years of scholarship between his writings and the Copernican Revolution.

The next time you find yourself outdoors during the night, look up. At first, you will see just a few points of light. Perhaps the bright stars of Sirius or Vega. And there might be a temptation to think that is all there is--that the sky is mostly empty, and there are only a handful of notable stars. But take the time to let your eyes adjust. If you can, go to a place with minimal light pollution. And look again. Where once there was seemingly empty space, there is now a host of stars, thousands in fact, if you find yourself in a remote enough place to see them. But it is not the sky that has changed but merely your perspective of it.

This is what it is like to research the gaps in the history of astronomy. As great as the contributions of the Romans, Greeks, and Galileo are, they are only a small part of the overall story, a handful of points of light in a dazzling tapestry of thousands. Throughout history, almost all cultures have studied the night sky, attaching their own stories and

significance to the movement of the heavens. Furthermore, astronomy often played a significant role in the lives of ancient civilizations, as alluded to by the structures they left behind (Taylor, 2019). Astronomy provides a natural way to investigate the lives and contributions of diverse people groups, yet this approach is not embraced in most classrooms. Yes, these historically neglected perspectives might be harder to find, especially initially, but their discovery and dissemination is essential to creating curriculum that reflects all learners.

The Shoulders of Giants

Learning about the contributions to astronomy during the Golden Age of Islam was like seeing the band of the Milky Way galaxy across the sky for the first time. As Neil deGrasse Tyson puts it, “Two thirds of all stars in the night sky with names have Arabic names. An homage to their ‘stellar’ navigational skills 1000 years ago, during the Golden Age of Islam” (Tyson, 2020). Most of the stars in the sky have Arabic names because astronomers of the Islamic empire observed and identified them hundreds of years before the advent of the telescope.

Listing the accomplishments of the scientists of this era would take far too many pages, but suffice to say that their contributions would echo through the centuries. From Muhammad ibn Musa al-Khwarizmi--whose Latinized name was Algorithmi--who codified the rules of aljabr--more widely known as algebra (Green, 2018)--to Abd al-Rahman al-Sufi who first observed the Andromeda galaxy and wrote “The Book of Fixed Stars” (Schilling & Tirion, 2019) the sciences would not be what they are today without the contributions of these scientists. Also, it is worth noting that scholars of this

era made many discoveries well before the Europeans that are later credited with them. For example, Iranian polymath Al Biruni born in 973 proposed a heliocentric model long before Copernicus, and under the direction of Caliph Al-ma’mun, scientists of the day were able to predict the circumference of the Earth to within 2% of the actual value (Green, 2018).

Another oft overlooked fact is that the scholars of this age are to thank for the preservation of so much ancient Greek and Roman knowledge through the Translation Movement. As Hank Green points out in his series on the history of science, "By 950, virtually every Greek scholarly text had been translated multiple times." (Green, 2018). Ibn Rushd--or Averroes in Latin--was a scholar who wrote so many commentaries on the works of Aristotle that he earned the nickname "the Commentator". It is bizarre that most astronomy curriculum praises the scholarship of the Greeks and Romans, but then overlooks those that preserved and expanded on that knowledge. As Isaac Newton wrote in 1675, "If I have seen further, it is by standing on the shoulders of giants" (Farnam Street, 2021). Science is a collaborative field that expands on the works of others; recognizing the contributions of those who came before is essential to practicing sound science.

Summary

In this chapter I discussed the importance of incorporating inquiry-based learning into science education by sharing how transformative it was for my own educational experience. Then, I identified some of the challenges of adapting engaging science lessons to distance learning that I discovered as I began my teaching career in the online

setting. A major concern in adapting lessons is equity, as resource disparity becomes even more pronounced when students are learning from home. I also discussed some of the unique and universal attributes of astronomy that make it an ideal template for developing engaging curriculum. Due to the coronavirus, many schools have transitioned to distance learning, increasing the importance of answering the question: *How can inquiry-based astronomy curriculum that is culturally sustaining and differentiated be effectively adapted to the online setting with student equity as a prime consideration?*

In the next chapter I will look at the literature on distance learning and adapting science courses to the online setting. I will look at this adaptation process through the lens of pre-pandemic and during. Next, I will focus on the role that resource disparity plays in effectively adapting inquiry science lessons to distance learning. Then, I will look at why it is important to provide curriculum that is culturally sustaining and differentiated to the needs of learners, with particular emphasis on the area of astronomy. Chapter Three will contain a description of my project: curriculum for a unit in high school astronomy that is adapted to the online setting with engagement and equity as key considerations. Chapter Four will be a reflection on the development of my project.

CHAPTER TWO

Literature Review

Introduction

As outlined in Chapter One, I have a vested interest in developing science curriculum in the online setting that engages learners of a variety of backgrounds. I have chosen astronomy because it is a useful template for science curriculum in general. The onset of the Covid-19 pandemic and the corresponding mass migration to distance learning makes developing effective curriculum a pressing concern for districts around the world. In this chapter, I will review literature that addresses facets of my research question: *How can inquiry-based astronomy curriculum that is culturally sustaining and differentiated be effectively adapted to the online setting with student equity as a prime consideration?*

To investigate this question, I will review the literature for five themes: distance learning, student equity, inquiry-based learning, culturally sustaining curriculum, and astronomy education. The first theme outlines the history of distance learning along with its advantages and disadvantages. The second theme of student equity looks into the impact of differing access to resources which become even more pronounced in distance and hybrid learning. The third and fourth themes investigate inquiry-based learning and culturally sustaining curriculum as hallmarks of engaging curriculum. I will look at the advantages and some of the challenges that accompany designing and implementing these types of lessons. The fifth theme investigates the history and recommendations for implementing the previous themes in astronomy curriculum.

Distance Learning

Distance learning--or online learning--is a model of education where students attend classes and collaborate with teachers in an entirely virtual manner. In practical terms, this means that students work from their own homes and complete lessons on either their own computer or a school provided laptop. This model usually includes a blend of synchronous and asynchronous learning (Daniel, 2021). Synchronous--or students and instructors working at the same time--modes of instruction include attending a Zoom meeting, meeting in Adobe LiveLesson, or even a phone call (Lemay, 2021). Asynchronous--or students and teachers working at different times--learning occurs when students work through their lessons individually--or with the help of a parent--and then reach out via email or text (Daniel, 2021).

While online learning has been around for longer than most realize (Perry & Pilati, 2011), it was adopted on a large scale at the onset of the Coronavirus pandemic in March of 2020 (Logothetis & Flowers, 2020). Distance Learning brings with it different benefits--such as student and teacher safety (Kelley, 2020) and increased accessibility (Burgstahler, 2006). But transitioning to distance learning brings with it many concerns as well, such as student equity (Ansari, 2002).

History of Distance Learning

As Tom Clark (2012) points out, online learning can be traced back to as early as the 1990s and has grown steadily over the years (Moore et al., 2012). Distance learning has been most heavily implemented in post secondary institutions, such as four-year universities and community colleges. Indeed, one-third of university students complete at

least one online course (Mcdaniel, 2013). It is not just higher learning that has embraced online instruction; it has also been adapted to the K-12 setting in a variety of formats. School district-led and virtual charter schools are the two fastests growing types of online learning (Moore et al., 2012). The two largest virtual charter schools, K-12 and Connections Academy, were founded in 1999 and 2001 respectively. Enrollment data shows that the pandemic only accelerated an ongoing trend of growing enrollment in online learning (Blagg & Gross, 2021). This raises the question, why are students transitioning to distance learning?

Advantages of Distance Learning

Throughout the pandemic, districts have utilized distance and hybrid learning for the safety of students and teachers (Daniel, 2021). Over a year and a half into the pandemic, vaccines for younger children have only recently been approved by the Food and Drug Administration (FDA) (Hensley, 2021). While it is encouraging that the FDA found that both the Pfizer and Moderna vaccines are safe and effective for children as young as six years old (The Associated Press, 2021), there has been--and continues to be--a large expanse of time where this age group does not have protection from the virus. Since the beginning of the 2021-22 school year, over a million children have contracted Covid due to the spread of the highly contagious Delta variant (The Associated Press, 2021). Fortunately, Covid symptoms tend to be less severe in children, but the Mayo Clinic (2021) points out there are still many concerns and unknowns about the long-term health consequences of having contracted the coronavirus (The Mayo Clinic, 2021). This concern for student safety has caused many parents and districts to opt for either fully

online or blended learning options which allows for safer social distancing (Daniel, 2021).

As previously mentioned, enrollment in distance learning was growing even before the onset of the pandemic, suggesting that there are benefits beyond student safety. One major advantage of online learning is that students have a more flexible schedule, including what hours students chose to work and the pace at which material is covered. (Mcdaniel, 2013). There are many benefits to having a later start time to the school day such as increased alertness and mental health benefits as described by Lo et al. (2018) of the Sleep Research Society. Attending school from home allows students to start their school later and acquire more sleep, even in a synchronous learning environment. Students enrolled in entirely asynchronous programs have even more flexibility in their schedules, allowing them to participate in extracurriculars with more rigid schedules such as professional sports (Bazin, 2018).

Distance learning also allows students to work through lessons at their own pace. Rather than having to adhere to the same classroom schedule as all other students, online learners do not have a bell dictating their day. If a concept is more challenging for a student, they can spend more time mastering the material (Mcdaniel, 2013). Conversely, if a student is already familiar with a topic, they can work through it more quickly. The freedom to dictate their schedules allows students to work through lessons more efficiently.

Other benefits of online learning lie in its potential to adapt material to the needs of the learner. Since courses are online, students can more easily access different

resources that cover lesson objectives such as videos, simulations, and even podcasts, allowing them to gravitate toward materials that most match their learning styles (Mcdaniel, 2013). This greater access to meaningful learning resources is especially helpful in courses like science. While schools might have vastly different laboratory resources, online simulations allow students to see different principles in action or to replicate an experiment that requires advanced technology (Iskander, 2007). Relatedly, research by Wallace (2009) and her fellow researchers at John Hopkins University Center for Talented Youth found that distance learning can be used “to provide appropriately challenging academic coursework to gifted students" (Wallace et al. 2009, p. #), even as young as elementary school.

Since students play a more active role in their learning, they have the opportunity to develop metacognitive skills--or the ability to reflect on one's learning--which will make them more effective learners, as Xu (2016) noted in their research on the development of metacognitive skills in online learning. Distance learning also has the potential to offer students timely feedback through utilizing programs that can grade certain types of questions automatically (Kassop, 2003). Receiving feedback closer to completing the work allows students to more effectively incorporate the feedback into their school work (McDaniel, 2013). If leveraged correctly, distance learning can help make students more independent learners.

Challenges of Distance Learning

Distance learning offers tangible benefits such as student safety and the potential benefit of making education more learner-centered. However, there are also many

concerns that accompany distance learning. These areas of concern can broadly be classified into student readiness to learn in the online setting and student equity. The former will be discussed here while the latter will be covered in the next section.

As Talbot (2010) describes in her book *Studying at a Distance*, being an online student requires a great deal of responsibility and organization. In the physical classroom, students have the learning space prepared for them and a class schedule that keeps them on track. When learning from home, students must exercise a greater degree of autonomy to compensate for the direct access to an instructor (Kemmer, 2011; Njoroge, 2020). While students may still have a planner that guides their schedule, it is up to them to log in for class and stay focused (Morales, 2007). Talbot (2010) also describes how students must also choose a learning space that is relatively quiet and free of distractions. Since students in the online setting have decreased external accountability factors, the student must be motivated and organized to work through lessons independently. Some students do have an adult who remains home with them throughout the school day; this variable will be discussed in greater detail under student equity.

Additionally, there are a host of potentially new technologies that need to be successfully navigated in order to access and submit assignments. Moreover, students need to advocate for themselves when they have questions or need support; educators are not in the same physical space as students so they are unable to decipher a puzzled look or see a raised hand. As Moore's theory of transactional distance describes, there is a greater barrier in understanding between teacher and learner with less dialogue (Bornt, 2011). This increased distance between students and their teacher and other students can

lead to decreased engagement since the setting can feel more impersonal (Harrington & DeBruler, 2020).

Effectively asking for help in distance learning requires communicating in a virtual manner (Beese, 2014). This could vary from writing an email, to a phone call, to using the chat function in a Zoom meeting, but they all have a learning curve of some degree, which can be challenging for those that have less exposure to technology, especially younger students (Harrington & DeBruler, 2020). Unsurprisingly, Akgoden

(2021) and colleagues found that technology skills and study habits were determining factors in a high school students’ success in the online setting.

Effective Strategies for Distance Learning

Given that success in distance learning is highly dependent on the consistency and motivation of students, teachers in the online environment need to effectively engage students. Getting to know your students and finding ways to build relationships in the online setting is a key factor to engaging students (Harrington & DeBruler, 2020). Another key factor in engaging students is designing relevant curriculum that uses multimodal resources, such as audio, visual, and kinesthetic (Mcdaniel, 2013). The next section provides an overview of student equity considerations that need to be accounted for when designing curriculum for distance learning.

Student Equity

The Center for Public Education (2016) notes that student equity provides all students the resources they need to be successful in school. Where equality treats all students as the same, equity acknowledges that some have greater access to resources

than others (Milken Institute: School of Public Health, 2021). This disparity needs to be accounted for when creating resources and working with students (Campbell & Storo, 1996). Since school funding is based on property tax, there are stark differences in classroom resources from school to school (Augenblick et al., 1997). Furthermore, resource disparity becomes even more pronounced when students are working from home rather than then in the same classroom (Campbell & Storo, 1996). In the online setting, Student Equity also entails access to a computer, a reliable internet connection, and the student's home learning environment (Tinubu & Herrera, 2020).

Impact of Pandemic on Student Equity

Italian researcher Scarpellini (2021) and colleagues who surveyed primary and middle schools throughout Italy about the effects of shifting to distance learning during the pandemic concluded that:

> Distance learning increased educational deprivation and social inequalities, especially for the youngest children, who lost almost one year of school. The situation was even worse for children with disabilities, who were neglected by the institutions. This period should be considered as an opportunity to correct the weaknesses of our school system. (p. 1)

What factors led to such stark differences in learner outcomes? In other words, what are the facets of student equity that need to be addressed when adapting curriculum to distance learning?

Access to Technology

Near the start of the pandemic, researchers Tinubu and Herrera (2020) of the Southern Education Foundation pointed out that "data on digital disparities reveal that nearly 20 percent of African American children ages 3-18 and 21 percent of families earning less than $40,000 per year have no access to the internet at home." During an advanced college chemistry lab forced to switch to remote learning, researcher Buchburger (2020) noted that access to the internet was one of the significant barriers to students meeting learning objectives in a timely manner. The "From Crisis to Opportunity" (2020) report mentions how if learning material is only available online, then students with no or limited access to a reliable internet connection will suffer.

Access to Materials

Additionally, access to a printer and physical supplies are also unknowns that must be accounted for when planning engaging lessons (Tushnet & Fleming-McCormick, 1995). Given many students' lack of access to a printer or reliable internet connection, many schools had to mail students learning packets, as noted by Fehling (2020) when summarizing a district's handling of the pandemic. In an effort to incorporate more hands-on activities, some teachers create lessons that use common household items (Flaherty, 2020). However, given that many families struggled to cover the cost of school supplies, it is difficult to determine what is "common" or "expendable", especially for those with lower incomes (O'Connor & Clawson, 2019).

The National Center for Education Statistics (2021) reported that before the pandemic,

"approximately 11.6 million children under age 18 were in families living in

poverty"; data also showed that students of color were more likely to live in poverty. Children living in poverty are far more likely to face food insecurity, meaning that they do not have access to the necessary amount of healthy food (Feeding America, 2021). Additionally, 1.4 million students in the United States deal with homelessness each year, (Cai, 2021). With so many students having unstable housing situations, access to learning resources and a stable learning space is even more fraught.

Student Support at Home

Varying levels of support at home also need to be considered when planning distance instruction. Some learners may have a parent who stays at home and helps them work through lessons while others are responsible for watching younger siblings while the parent is away at work (From Crisis to Opportunity, 2020). High school students may themselves be responsible for working a job to help support the family by bringing in additional income, leaving less time available for school work (Singh et al., 2007). The pandemic has been especially challenging for students enrolled in special education programs who received a significant decrease in support when working in the online setting (Neff, 2020).

Equity-centered Design

Given the incredible disparities that exist in student resources and support, how can curriculum be designed to meet the needs of such a vast array of students? Working with Harvard University, the Center for Applied Special Technology (CAST) has designed a framework termed Universal Design for Learning (UDL) which aims to make content accessible to all learners, especially those in special education programs (Darvasi,

2020). Designing for the student with the most barriers to learning improves the learning experience for all students (Capps, 2017). As CAST outlines, the three staples of UDL are engagement, representation, and action and expression, with each category designed to target a different dimension of learning (CAST, 2018).

Engagement speaks to the “Why?” of learning (CAST, 2018). Curriculum that engages students helps them understand the importance of the content by showing its relevance to everyday life. Furthermore, it incorporates student choice so that learners can delve deeper into the topics that interest them. Engaging curriculum also increases student's involvement in the learning process by giving them opportunities to reflect on their learning and assess their progress. The mark of an engaged student is that they understand the purpose behind lessons and are motivated to complete them (CAST, 2018).

The "What?" of learning is addressed under representation of the UDL framework (CAST, 2018). Especially pertinent to online learning, curriculum that is designed to be accessible to all students needs to be presented in a variety of ways. Commonly referred to as multi-modal, lessons should be presented in a visual, auditory, and kinesthetic media. Having multiple ways to access the information ensures that it can be used by students with disabilities while also catering to different learning styles (Darvasi, 2020). Furthermore, accessible curriculum clarifies symbols and vocabulary, which aids those with less prior knowledge of a topic along with those learning English as a second language. This area of UDL also entails aiding student comprehension by highlighting patterns and helping them to recognize larger themes across the content. Lessons have

successfully accounted for vital aspects of representation when students have the resources and knowledge they need to navigate new learning (CAST, 2018). Lastly, action and expression outline the "How?" of learning. Lessons should ensure that the tools students will need to navigate material are readily available. Content should be differentiated, providing multiple ways for students to acquire and demonstrate proficiency. This entails allowing students to use a variety of media such as videos, drawings, and music. Lessons should also incorporate manipulatives such as physical models and interactive online activities. Additionally, curriculum should aid students in making plans on how they will navigate through lessons. Lessons have fully considered all aspects of UDL's action and expression category when learners are able to strategically work towards their goals (CAST, 2018).

The overarching theme of Universally Designed Curriculum is providing a wealth of options for how material is presented and navigated. Teachers cannot control the external factors that pose potential barriers to learning. However, they can aid students by making their curriculum more accessible, providing the flexibility that students need when learning in the online setting (Darvasi, 2020). The next section examines a hallmark of engaging science curriculum: inquiry-based learning.

Inquiry-based Learning

Inquiry-based learning is when students start with a question and arrive at their own conclusions through exploration and experimentation (Pedaste et al., 2015). Where didactic learning is teacher-focused, and positions the instructor as the giver of knowledge, inquiry-based learning is student-centered and helps students have agency

over their own learning (Bulba, 2015). The phases of inquiry are orientation, conceptualization, investigation, conclusion, and discussion (Zacharia et al., 2015). Like UDL, inquiry-based learning has a great deal of potential for helping to engage students in the online setting (West et al., 2021).

Advantages of Inquiry-based Learning

An advantage of inquiry-based learning is that there is a higher level of student engagement since curiosity is the driving factor (Wolpert-Gawron, 2016). Rather than being told what to learn, lessons are designed in a way where students want to investigate further. Additionally, this method of learning better prepares students to navigate a complex society by teaching them to analyze data and draw conclusions from evidence (Bulba, 2015). Furthermore, inquiry-based learning closely aligns with the scientific process: Students start with questions, create a hypothesis, make observations and analyze their data, present their findings, and then reflect on the learning process (Wolpert-Gawron, 2016).

Challenges of Inquiry-based Learning

Challenges to implementing inquiry-based learning include having the needed resources for investigations (West et al., 2021). Ideally, supplies for experiments are provided by the school, but there are barriers that prevent this from becoming a reality. In distance learning, students do not have access to a laboratory and supplies in the same manner in-person learners do (Miles & Wells, 2020). This lack of access to physical lab spaces means that investigations in the online setting must find alternative methods for conducting experiments. Of course, it is worth noting that even in person there are vast

differences in laboratory resources due to disparities in school funding, so finding alternatives to advanced, in-person labs extends beyond distance learning (Augenblick et al., 1997).

Inquiry-based Learning in the Online Setting

One method to allow students to conduct experiments at home involves purchasing laboratory kits with needed supplies. The advantage of this approach is that students are able to do experiments synchronously with instructors and classmates since everyone is provided the same materials (West et al., 2021). A disadvantage to this approach is that supply kits are expensive, varying from one-hundred to two-hundred dollars, depending on the course (Carolina Distance Learning, 2021). Unfortunately, this cost is often placed upon the student, which raises issues of access and equity (Flaherty, 2020). Additionally, the materials are less advanced than what students would be able to use within a school's laboratory (West et al., 2021).

Another method to circumvent the access to a lab is to design experiments that use common household supplies. Al-Soufi (2020) and colleagues were able to design a chemistry lab around photometry and dye-absorption using common materials from within students' kitchens and found students were able to meet outcomes similar to in-person learning. Using common household items is less expensive than purchasing a kit, but it still presents challenges. Differences in materials can lead to communication barriers, creating uncertainty in carrying out the laboratory procedure (Buchberger, 2020). As mentioned earlier, requiring students to use materials procured using their own

income generates an unfair burden for lower income families that could potentially exclude learners (O'Connor & Clawson, 2019).

The other major approach to labs in distance learning utilizes the primary medium for course instruction: the internet. Online simulations can be designed to mimic aspects of in-person learning or they can be simplified models that help students to understand principles behind experiments in a more visual way (Jones, 2018). Furthermore, virtual labs do have advantages over in-person labs due to their format. Online simulations have the benefit of requiring less time to implement since they do not have to be physically set up and taken down (Caño de las Heras et al., 2021). They are also more accessible, and students can work on them without time restraints (Faulconer & Gruss, 2018). The lack of physical materials also means not having to spend money on expensive lab equipment and supplies (Kapici, 2019). Virtual labs also offer greater freedom to experiment since they do not carry the same safety limitations as a physical lab space (Jones, 2018).

Given the unique advantages of virtual labs, perhaps it is unsurprising that research revealed that students at the college level who completed both physical labs and simulations did significantly better than those who only completed physical labs (Campbell et al., 2002). Kapici (2019) and fellow researchers found that simulations alone produced learning outcomes similar to those of the in-person lab for middle school science courses. Caño de las Heras (2021) and colleagues also deemed virtual labs a suitable substitute for high level college chemistry courses in terms of knowledge acquisition. However, when reviewing the literature upon the effectiveness of virtual and

remote labs, authors Faulconer and Gruss (2018) note that there is a lack of research on students' success in physical lab courses after completing virtual labs as an alternative.

Best Practices for Inquiry in Online Science Labs

In a review of the available literature on virtual labs, Faulconer and Gruss (2018) report that engagement with students was essential for positive learning outcomes. Clear guidance is essential due to the distance between teacher and student (Gamor, 2021). When investigating the support given to students in virtual labs, Zacharia (2015) and fellow researchers discovered that more guidance is given during the investigation phase, and there is a need for more structured support during the orientation to the investigation and discussion of findings. Chatterjee (2021) and many others point out the need for more research in the area of best pedagogical practice for virtual and remote experiments. The next section looks deeper into the importance of engaging all students through developing culturally sustaining curriculum.

Culturally Sustaining Curriculum

Culturally sustaining curriculum values and incorporates diverse cultural and linguistic perspectives (Hanover Research, 2020). Paris (2017) and colleagues describe how culturally sustaining pedagogy has an asset based view of students' diverse backgrounds--what unique perspectives and skills do students bring to the classroom--rather than deficit-based--what do students struggle with? Curriculum that is culturally sustaining will represent a variety of cultures and voices (Ladson-Billings, 1995). Additionally, it acknowledges different ways of knowing: experiential knowledge vs. empirical data collection (Howard & Kern, 2019).

Importance of Culturally Sustaining Curriculum

It is no secret that the scientific field has a lack of diversity. Author Guterl (2014) of Scientific American points out that while white males make up one third of the United States population, they compose half of the scientific and engineering workforce. Of the engineering degrees awarded in 2016, 60% of the recipients were white (National Center for Education Statistics, 2018). Looking at doctoral degrees awarded in physical and earth science in 2019, 75% are awarded to white individuals, followed by 9% Asian, 7% Latino or Hispanic, and only 2% Black with the remaining 6% belonging to more than one race (Fernandez, 2021). This lack of representation is problematic since diversity and the alternate perspective it brings is essential to quality science (Gibbs, 2014). Furthermore, less potentially qualified individuals entering the field means a loss of talent that negatively affects everyone since society directly benefits from advances in science and technology (Multicultural Development Center of Iowa, 2021).

In 2006, the National Research Council's America's Lab Report noted that science lessons needed to be more interactive to engage all students, especially those that have been historically marginalized (Parsons, 2019). Yet, the American education system remains far from reaching the goal of equal access and opportunity. One of the barriers to students of color entering the sciences is the lack of representation within the science curriculum. When reviewing college biology textbooks, Brookshire (2020) found that of the scientists discussed, only 8% were scientists of color. Portraying mainly white, male scientists conveys the idea that science is mainly done by individuals with this

appearance, sending the message to students of color that they do not belong in the sciences (Goldfarb, 2020).

Culturally sustaining curriculum has benefits for all students. Including the scholars and accomplishments of different backgrounds helps students to recognize that science is a diverse enterprise. Furthermore, incorporating different viewpoints can help students to think more critically about scientific concepts by helping them to examine concepts through new lenses (Baker, 2016). Researchers Howard and Kern (2019) have also demonstrated that incorporating narratives of different geographical areas is an effective way to engage students. Additionally, McMillan (2013) and fellow researchers also found that honoring the contributions of different cultures, especially indeginous knowledge, helped students to appreciate different worldviews. Presenting the knowledge of different cultures can also play an important role in helping preserve languages, especially indigenous ones that are in danger of extinction (McKinley, 2005). The upcoming section exames how culturally sustaining curriculum can be developed within the field of astronomy.

Astronomy Education

Astronomy stems from the Greek word "astronomos", which means "the laws of the stars" (Etymology, 2021), but the purview of astronomy is so broad that it can perhaps be best summarized by the title of Douglas Adam's third installment of *The Hitchhiker's Guide to the Galaxy*: "Life, the Universe, and Everything" (Adams, 1982). Indeed, the field encompasses not just stars, but all celestial bodies--or objects in the sky--and the nature of the universe itself (Redd, 2017). Astronomy is deeply rooted in

physics--the branch of science that uses mathematics to model the processes of our world (Brown et al., 2021)--and chemistry--the branch of science that studies the nature and interactions of matter (Usselman and Rocke, 2021).

With such a large subject area, it is necessary to narrow the scope of learning.

However, like other disciplines, astronomy education often falls into the pitfall of only sharing the dominant narrative, which is to say white and male (University of Michigan, 2021). Despite thousands of years of human history, astronomy curriculum tends to only describe the contributions of Greek and Roman astronomers along with the European astronomers that participated in the Copernican Revolution (Pearson, 2020). Given the incredibly long history of astronomy in comparison to other scientific fields, it has great potential to include the views and accomplishments of diverse communities throughout history (Fraknoi, 2016).

Astronomy also presents a wealth of opportunities to include Indigenous knowledge of the tribes local to Minnesota: the Ojibwe and Dakota (Lee et al., 2014). The Minnesota Department of Education (2021) mandates that Indigenous knowledge be integrated into science lessons. However, a survey of the secondary science teachers at Minnesota Connections Academy revealed that there was no mention of Indeginous knowledge within the curriculum (K. Laverns, K. Browser, and E. Johnston, personal communication, September 24, 2021).

Making Astronomy Inclusive

Oddly, there are no Minnesota State Science Standards that directly link to astronomy at the Earth science 9-12 level (Minnesota Department of Education, 2021).

Astronomy professor Impey and colleagues (2020) outline suggestions such as examining the art and stories different cultures have around astronomy. As Rosenberg (2013) and colleagues of the International Astronomical Union point out, astronomy is one of the oldest sciences that ties into the everyday lives of all cultures. Looking at how diverse groups used astronomy to tell time and prepare for changing seasons gives insight into other cultures and scientific phenomena that we still observe today (Rosenberg et al., 2013).

In regards to representation, Impey (2020) notes the importance of pointing out the nationality of European scientists--for example Italian Astronomer Galileo Galilei--so that students do not think being of European descent is the default. Impey also includes a short list of individuals from a variety of backgrounds who made incredible contributions to astronomy that should be studied such as Hypatia, Zu Chongzhi, Shen Kuo, Muhammad ibn Musa al-Khwarizmi, Subramanyan Chandrasekhar, and Chushiro Hayashi, to name a few (Impey et al., 2020). Impey (2020) also notes the importance of explaining metaphors that are based on cultural assumptions of knowledge such as “the Goldilock Zone”. This principle of explaining culturally-dependent metaphors is a hallmark of accessible curriculum as outlined in the Universal Design for Learning (CAST, 2018).

Conclusion

This chapter provided an overview of research regarding distance learning, student equity, inquiry-based learning, culturally sustaining curriculum, and astronomy education. Distance learning is the setting for my project while student equity focuses on

considerations that need to be made when designing curriculum in the online setting. Inquiry-based Learning and culturally sustaining curriculum play important roles in engaging learners from a variety of backgrounds. Lastly, astronomy is the area of science in which I will create curriculum that answers my research question: *How can inquiry-based astronomy curriculum that is culturally sustaining and differentiated be effectively adapted to the online setting with student equity as a prime consideration?* A theme across these topics is that there are various barriers to student learning, so curriculum in the online environment needs to provide multiple options for students to learn and demonstrate proficiency in new concepts.

Chapters One and Two have highlighted the need for engaging, culturally sustaining curriculum in the online setting. Chapter Three will contain an overview of the project, including a description of the project, rationale for its development, and the intended audience. Future chapters will reference the research outlined in this chapter.

CHAPTER THREE

Project Description

Introduction

This chapter outlines the details of the project that seeks to answer the research question: *How can inquiry-based astronomy curriculum that is culturally sustaining and differentiated be effectively adapted to the online setting with student equity as a prime consideration?* Here, I will describe the rationale behind my project and the learning frameworks used and the research that supports them. Then, I will describe the intended participants and setting for the project along with the assessments that will be developed to measure learning outcomes. Finally, I will describe the timeline of the project's development.

Rationale

As Chapter Two described, an advantage of online learning is its potential to engage students using a variety of modalities (Mcdaniel, 2013). Yet when I encounter lessons made for the online setting, this opportunity to individualize learning is often squandered. Instead, lessons are simplified and streamlined. In the online school at which I currently teach, the premade lessons consist almost entirely of reading as a way to present information, and then students are assessed through multiple choice or true and false questions (Pearson, 2020). In this format, learning is superficial, confined to the bottom rung of Bloom's Taxonomy: recall. This approach teaches students to memorize rather than problem solve. Furthermore, overwhelming students with information without

showing them the relevance of the learning leads to low student engagement, which is critical to success in online learning (Harrington & DeBruler, 2020). ***Inquiry-based***

My aim is to create a curriculum that kindles curiosity. Lessons are structured so that students are able to ask and answer questions based on their own observations. Rather than being told what to memorize, students recognize patterns and draw conclusions from their data. I applied experiential learning theory so that students can connect their learning with new experiences and apply their knowledge to real-world contexts (Mcleod, 2017). Developed by David Kolb in 1984, Experiential Learning Theory (ELT) synthesizes the work of many prominent educational psychologists such as Piaget and Dewey who described the importance of providing new experiences to enable new learning (Kolb, 2021).

Using an inquiry-based approach, students see that we live in a world with far more questions than answers. Furthermore, lacking an answer is not the ending point, but a starting point. Students are active participants in the scientific process as they recognize that each unknown is an invitation to exploration.

Culturally Sustaining

I wanted to create curriculum that reflects the diversity of its learners. Currently, the existing curriculum at the online institution where I teach is incredibly Western-centric. Despite astronomy being arguably the oldest science, the Pearson (2020) curriculum--like most astronomy courses--acknowledges only the contributions of the ancient Greeks and Romans before jumping a thousand years to discuss the European

scientists involved in the Copernican Revolution. Focusing only on the accomplishments of Western scholars sends the insidious message that science is only done by individuals with this appearance.

All curriculum should be inclusive, representing the students taught within the classroom. As Chapter Two highlighted, science curriculum frequently fails to meet this culturally sustaining standard, which is highly unfortunate because astronomy provides natural ways to highlight the lives and scientific accomplishments of cultures that are typically ignored within the science classroom. Given the setting, my curriculum pays particular attention to the Indigenous knowledge of the Ojibwe and Dakota, the groups that have historically lived--and continue to reside--in Minnesota.

I also tied in the contributions to astronomy from the Golden Age of Islam. Typically, this era is overlooked in curriculum, but the work of Arabic scholars during this age forever shaped mathematics and sciences (Green, 2018). Besides preserving the knowledge of the Greeks and Romans--making the later European Renaissance possible--Arabic scholars made incredible scientific advances, often well before the Europeans who are credited with being the “first " to do so.

Besides righting historical inaccuracies, focusing on the scholarship of Arabic scholars is useful for analyzing the field of science along with its limitations such as cultural bias. For example, despite the Greeks making observations of the night sky, their models for the motion of the Sun and planets were inaccurate due to their preoccupation with circles, which they regarded as the perfect shape. They believed that the heavens--linked to the gods--had to be perfectly ordered, and this cultural bias prevented

them from accurately predicting the motion of celestial bodies. It also led to the inaccurate model of the Earth at the center of the universe. Arabic scholars, on the other hand, based their models on observations, allowing them to critique the Greek models of the cosmos and propose heliocentric models--where the Sun, not the Earth, is the center of the Solar System--as early as the 900s C.E.. Analyzing how different cultures understood and applied astronomy helps students think critically about scientific inquiry and the role it plays in our lives today.

Differentiated and Student-Equity Centered

As described in Chapter Two, there are many barriers to students learning in the online setting that must be taken into consideration when designing curriculum that is accessible for all learners (Tinubu & Herrera, 2020). Some learners have access to a reliable internet connection while others do not (Buchburger, 2020). Some may have a parent supporting their learning at home while others are working independently (From Crisis to Opportunity, 2020). For some, using “common” household items is not an option due to financial constraints (O’Connor & Clawson, 2019). Providing only one option for completing a lesson would invariably discriminate against different groups of students.

My curriculum incorporated the principles of Universally Designed Learning developed by Harvard’s Center for Applied Special Technology (CAST) (2018) so that all students can have a meaningful learning experience. A hallmark of accessible curriculum is that it uses multiple modalities for information and student engagement. My curriculum will have multiple ways for students to explore new information such as

videos, simulations, and articles. Students will be able to select the format that best aligns with their learning style and resources to which they have access.

Project Description and Application

I created a four-week long high school astronomy unit for the distance learning setting. Lessons are designed to provide flexibility and maximize student choice while still assuring that all students achieve the desired learning outcomes. High school Earth science does encompass space science standards, so portions of the class could be adapted to this required course. Since Earth Science is also taught in sixth grade, activities could also be simplified to make them suitable for younger students. While the curriculum is designed with the online setting in mind, the varied options available allows activities to be utilized in synchronous, in-person learning settings such as physical classrooms and environmental learning centers.

Framework

The project was designed using the principles of Backwards Design, as described in Understanding by Design (Wiggins and McTighe, 2008). In this approach, the learning outcomes are identified first, followed by determining assessments that will demonstrate proficiency. The last step is to design activities that support developing the relevant knowledge and required skills.

Here are the learning outcomes as outlined by the Pearson (2020) designed course "Introductory Astronomy", in which my unit would be implemented: By the end of the course, the student will be able to: Assess the nature, scope, and evolution of the Universe; Apply fundamental concepts underlying astronomy;

> Evaluate the evolution of scientific ideas in astronomy; and Analyze data to determine patterns, relationships, perspectives, and credibility (Course Summary)

The unit is titled "Cycles in the Sky" and helps students link observable patterns of the movement of the Sun, Moon, and constellations to the Earth's place in the universe. The motion of the Sun and Moon in relation to the Earth is linked to the fundamental principles of gravity and orbits. Meanwhile, the changing view of constellations allows students to learn about the tilt of the Earth's axis and how proximity to the Earth's poles impacts the observer's view of the night sky. This unit also explores the link between developing technology that enhances methods of observation and more accurate models of the universe. Students analyze the data of historical astronomers to test the validity of different models of the Solar System, namely heliocentric versus geocentric.

Participants and Setting

The curriculum is primarily intended as a high school astronomy elective in the online setting. The elective is open to all high school students, but it is most frequently taken by eleventh and twelfth grade students. At the moment, there are eighty students enrolled in the two high school astronomy electives offered. Presently, I teach at an online public charter school that has its main office located in St. Paul, Minnesota. As of November 2021, the school's enrollment is around 4,200 students from K-12. All staff teach remotely as the school is fully virtual, even in non-pandemic times. Students are enrolled from all over the state, coming from both urban and rural areas. From an

astronomy perspective, this means that some students have access to dark skies while others live in areas with greater light pollution.

Assessment

In the spirit of Universal Design for Learning, lessons and assessments are differentiated. Rather than being confined to multiple choice questions, students answer short answer questions after exploring their preferred resource. At the end of the unit, students develop a project centered around an archaeoastronomical site, in other words, an ancient building whose construction reflects astronomical phenomena. Given the wide array of potential formats for the project, rubrics are used to assess the acquisition of desired skills and incorporation of key concepts.

The curriculum itself is assessed through an array of research-based methods. To ensure that the curriculum is inquiry-based, I will use the Rubric for Inquiry-based Teaching and Learning developed by Harvard Graduate School of Education (2020). The accessibility of curriculum for all learners is measured using Universal Design for Learning Guidelines (2018). The culturally sustaining nature of the curriculum is evaluated using New York University's Culturally Responsive Curriculum Scorecard (Bryan-Gooden et al., 2019). When the curriculum is implemented, it will be evaluated based on student engagement and their feedback which will be collected using Google Forms.

Timeline

The unit is four weeks long and would be the first unit covered in the semester long course. At the college level, astronomy is usually offered in fall semester due to

Minnesota's cold and long winters that pervade much of spring semester, making outdoor labs--a staple of astronomy--challenging. In the high school setting, the weather is generally not taken into consideration since observing the night sky is only possible well after regular school hours, so astronomy is offered in both the fall and spring. Relatedly, my curriculum can also be utilized in either semester. Ideally, the weather is mild enough that students can do brief outdoor observations even during winter. However, if Minnesota does lean into its borderline arctic nature, then students can still conduct investigations using the online simulations.

The unit was developed in the spring semester of 2022, so from the months of

January to May. Many of the ideas that transformed into full lessons came from working with my current students in the existing astronomy courses and researching culturally sustaining and equitable instruction for Chapter Two.

In accordance with Backwards design, I first started with assessing the needs of my learners. Next, I determined the assessments that would provide proof of proficiency. Finally, I began designing inquiry-based lessons that allowed students to develop the desired skills and knowledge.

The project was submitted in April 2022. Ideally, it will be implemented by fall semester 2022. However, there are many bureaucratic and some technical barriers that prevent my curriculum from being efficiently implemented in my current setting. It can still be used, but the highly outdated Learning Management System (LMS) that Pearson utilizes means more work for instructors and muddled communication with students. The ideal method for implementation would be Pearson actually integrating an engaging

curriculum into their LMS, but this is as likely as light escaping a black hole. In reality, the most probable scenario for this curriculum to be implemented in its intended form is in another online-based high school with a less restrictive LMS that allows teachers to design and effectively share lessons.

Summary

This chapter explored the parameters of my project centered around the question: *How can inquiry-based astronomy curriculum that is culturally sustaining and differentiated be effectively adapted to the online setting with student equity as a prime* *consideration?* First, I described the rationale and how each parameter of my project fits into the larger whole. Then I provided an overview of the curriculum's framework, including the learning objectives and a broad overview of the unit. Following was a description of the setting, participants, assessments for learning, and the timeline for implementation.

Chapter Four will provide a reflection on creating the project and its significance to the field. Previous chapters will be revisited as I discuss new learnings generated through research and development of the project. Chapter Four will also include implications of the project and related research questions for future curriculum projects.

CHAPTER FOUR

Conclusion

Introduction

This chapter provides a reflection of the development of the project that seeks to answer the research question: *How can inquiry-based astronomy curriculum that is culturally sustaining and differentiated be effectively adapted to the online setting with student equity as a prime consideration?* In this chapter, I will reflect on my learnings as a writer and researcher while also examining resources from the literature review that had a profound impact on my project. I will discuss the project's policy implications. Next is an overview of its limitations and areas for future research. Finally, I will discuss the project's applications and benefits to the field of astronomy education.

Major Learnings and Critical Resources

While creating my capstone project, I learned to embrace Voltaire's philosophy of "The perfect is the enemy of the good" (Patel, 2022). Early in the development of my project, I had many ideas of what I wanted my project to be. Namely, I wanted to fully embrace the principles of Universally Designed Learning (CAPS, 2018). My plan was to have an online option, an in person option, and even a local alternative for each activity. I originally planned to maximize student choice by presenting an abundance of options. However, two aspects of the project led the creation of my lessons in a different direction.

The first limitation was the online format of my project. When I was completing my undergraduate degree in science education, I took an educational psychology course that emphasized and implemented differentiation. For each unit, the professor presented

us with an excel spreadsheet. Each column contained a topic that we needed to cover followed by rows of options. Each option would be worth a certain amount of points, and the only constraints were that we needed to do at least one activity for each topic (column) and that we earned the required total of points for the whole unit. As a student, I loved the design of the course. The flexible structure allowed me to complete the activities that appealed to me the most while still covering all the required material.

My original plan was to offer something similar in the lessons I designed. I even contemplated creating a similarly designed grid and then allowing students to select activities from it. However, Moore's Theory of Transactional Distance, which outlines how there is a greater barrier in understanding between teacher and learner with less dialogue (Bornt, 2011) changed my mind. The decreased dialogue in the online setting mandantes that communication is clear.

While having a multitude of options is great from a differentiation perspective, a flexible format can also lead to confusion as to what exactly is expected. Furthermore, having too many options can actually be counterproductive as student learning can be stalled as they struggle to decide which option to do (The paradox of choice, 2022). I encountered these issues when I first started designing my lessons. It was great to have so many options, but providing clear and direct instruction was challenging. Each additional option and the necessary explanation diluted the clarity of instruction.

I also encountered the second great constraint on the development of this project: time. As awesome as it would be to have a fully fleshed out differentiation option for each activity inside every lesson, developing the instruction to the needed level of detail

was not feasible within the time constraints of the project. I wanted my project to meet the needs of every learner by anticipating every obstacle and providing an accommodation for each scenario. And in a theoretical state, it could. When the project was only an idea, it was limitless.

But the process of creation grants form. And each form has its advantages and drawbacks. It is the responsibility of the creator in all fields to navigate these tradeoffs and make decisions that will create the most good for the most people. There is no perfect curriculum that meets the learning needs of every student. Students are simply too diverse for any one design to meet them each in their respective zone of proximal development, simultaneously offering the necessary scaffolding and real world connections.

But of course, some designs are better than others. When selecting the content to include, I had to consider the needs of my learners, and decide what was most important. In the online setting with its communication barriers, the need for clarity outranked boundless options. My aim in developing my lessons was that students would always have a clear path forward. I scaled down my choices to focus on the online setting. This decision allowed me to focus on my area of expertise and acted as an equalizer for lesson development. I did not want to exclude students who lacked certain "common" household items or make presumptions about the support they had had at home by including activities that required help from a sibling or adult. Instead, the only requirement to complete the lessons would be a computer and an intermittent connection to the internet. My lessons still provide differentiation but in a structured manner. Students answer the same questions along the way, but how they acquire the information is open

ended. I still embrace the Universal Design for Learning (CAST, 2018) principle of differentiation by using a variety of modalities that students can use to explore new concepts. Furthermore, the culminating assessment on researching an ancient site that relates to astronomical phenomena provides a plethora of opportunities for student choice in content and format. Finding a balance between unlimited differentiation and clear communication was challenging, but ultimately the clarity of a consistent lesson format will be more beneficial to my students' learning in the online setting.

Another essential aspect that guided the development of my project was that it be culturally sustaining. To briefly recap, research shows that far too often science textbooks fail to reflect the diversity of their learners (Brookshire, 2020). This lack of representation can then further deter students of color from entering scientific fields (Goldfarb, 2020). Furthermore, curriculum that contains diverse viewpoints benefits all students by promoting critical thinking (Baker, 2016).

The text *Astronomy Education* by Impey et al. (2020) was an invaluable resource as I sought to design a curriculum that reflected the diversity of its learners. While the text focuses on providing suggestions for astronomy at the college level, much of the advice in chapter 12 around how to make astronomy inclusive can be easily translated into the online setting. Impey et al. (2020) point out that far too often examples provided within lessons lack real world significance for students, but the earlier concepts in astronomy such as time keeping and the motion of celestial objects provide an abundance of opportunities to discuss the viewpoints of oft neglected cultures. The author goes on to cite the power of including stories and media that students can connect to.

I capitalized on this guidance firstly through the selection of my unit's content. Astronomy is an incredibly vast field, and I opted to design a unit around phenomena that could be observed from Earth precisely because of its opportunities for inclusion. Before the invention of the telescope in 1608 (Galileo and the telescope, 2022), all humans were on an equal playing field for observing the night sky. This ubiquitous access translates to an immense amount of stories that reflect the movement of celestial objects. In addition to recording scientific phenomena, these stories provide insight into the lives and values of diverse people groups.

Naturally, stories reflecting astronomy from all over the world is a vast pool from which to draw. Much like with selecting activities that promote differentiation, there is an initial impulse to include as much as possible. But, here again, an overload of options is counterproductive. As Wiggins and McTighe (2008) describe in *Understanding by Design* the role of an educator is not simply to cover material but to uncover it. My aim was not to simply expose students to new information but to foster meaningful interactions with culturally diverse materials.

In order to weave a cohesive narrative and enhance real-world significance for my students, I primarily focused on including Indigenous science knowledge of the Ojibwe and Lakota, who reside in Minnesota. *Ojibwe Sky Star Map Constellation Guidebook : An Introduction to Ojibwe Star Knowledge* by Lee et al. (2014) and other resources made available on the Native Skywatchers website were indispensable in creating lessons that incorporated Indigenous perspectives. Furthermore, *Star Stories of the Dreaming: A Study Guide for Australian Indigenous Astronomy* developed by ABC Education (2019)

provided a helpful template for how to incorporate Indigenous science knowledge into astronomy lessons.

The process of designing culturally sustaining astronomy lessons was humbling. Each story that I unearthed was a reminder of just how much I still had to learn. As Aristotle put it “The more you know, the more you realize that you do not know” (Ardalis, 2019). The process was akin to learning another language. Just as my native tongue is one way of communicating, my western perspective is only one way of seeing the stars.

Project Policy Implications

While I genuinely enjoyed researching these diverse star stories, my lack of prior knowledge highlights a conundrum afflicting the current educational initiative of integrating Indigenous science knowledge into Minnesota's state standards. As described in Chapter One, the state's new science standards outline that educators need to incorporate the knowledge of the Ojibwe and Lakota (Minnesota Department of Education, 2021), yet a parallel mandate is missing within teacher education programs. In order for future educators to be adequately prepared to meaningfully incorporate Indigenous Science Knowledge into their curriculum, they need to receive proper training and resources.

It is inevitable that some teachers during the transition period–such as myself–have a greater burden of self-teaching. But in order to reconcile the disparity between expectations and resources, there needs to be legislation that outlines how

Indigenous science knowledge will be incorporated into teacher preparation programs. If nothing else, this external mandate is necessary as a quality control measure.

Limitations and Future Research

A major limitation of my curriculum is that it does require students to have a computer and access to the internet. Since I teach in the online setting and it is expected that students have these resources, it should not be too much of a limiting factor for my students, but it does potentially limit the application of the curriculum in other settings. Furthermore, technology is a firm adherent to Murphy's Law, so having contingency plans for lessons when students do not have access to reliable internet would improve the utility of the curriculum. Developing activities that still meet the same lesson objectives but can be completed offline would be an area of future research. As discussed in Chapter Two, any offline activities would need to account for student resource disparity (O'Connor & Clawson, 2019).

Another limitation of my project is that it is designed to be used within Minnesota since much of the Indigenous Science Knowledge included is that of the Ojibwe and Lakota. The number of local examples increases the relevance for students from this region, but those from much farther away might lack familiarity with some examples used. For example, the Ojibwe equivalent to the Little Dipper asterism is *Ojiig*, or The Fisher, a mammal local to Minnesota's northern forets. Similarly, simulations and discussions are set to reflect observations that can be made from Minnesota's latitude.

Project Applications and Benefits to Field

Rather than being directly adopted by teachers outside of the state, the Cycles in the Sky unit could serve as a template for other educators wishing to design astronomy lessons that incorporate Indigenous science knowledge in an inquiry-based manner. Local examples from Minnesota are most prominently incorporated into lessons two through six, so these are the lessons that would need the most adaptation by someone from outside the state. It is also worth noting that exploring stories from outside one's latitude is beneficial to students. Exploring how the story from one group comparis to another in a distant location can help students understand how the observer's location affects their view of the stars–and why star charts are based on latitude.

For educators who reside in Minnesota, the curriculum can be more readily implemented. The curriculum was designed for students working online, but the resources and activities could easily be adapted to a hybrid or in-person learning setting. All students need to complete the lessons is a computer and internet access, so having extensive materials is not a limiting factor. A brief perusal of the lessons will reveal that point values for activities have intentionally been left out, so that teachers can assign values that most align with their respective grading scales.

My project benefits the profession by providing a tangible example of how Indigenous science knowledge can be incorporated into astronomy curriculum. While there are great resources available from websites such as Native Skywatchers, my lessons go a step further and provide interactive activities to help students appreciate how the stories of the Ojibwe and Dakota record astronomical phenomena. Furthermore, the

varied content demonstrates how Indigenous Science Knowledge fits naturally into far more topics than just the handful of times it is explicitly outlined in the standards. More broadly, my curriculum presents the history of astronomy in a culturally sustaining manner. Rather than taking a Western-centric approach typically seen in astronomy courses–which starts with the Greeks and Romans and then jumps a thousand years to Europe–my course acknowledges the contribution to astronomy by diverse people groups. Lessons include observations from arguably the world's first astronomers–the Aboriginal Australians–along with Indigenous groups local to Minnesota such as the Ojibwe and Lakota. Additionally, lessons include contributions from scholars made during the Golden Age of Islam. Sharing a continuous timeline with students allows them to appreciate the contributions of Arabic scholars who preserved and added to the ancient knowledge of the Greeks. It also helps students to see that the development of knowledge is a process rather than a spontaneous event. Lessons further highlight that astronomy is a shared human endeavor by giving students the opportunity to research an archaeoastronomical site. As mentioned before, it would be impossible to include all of the accomplishments of ancient stargazers within one course, but introducing students to a few and then allowing them to research one in depth as a culminating project provides a nice starting point. Their explorations will help them appreciate that astronomy is truly one of the oldest sciences with collaborators all over the world.

Another benefit of the curriculum is that it provides examples of how to create engaging curriculum in the online setting. Far too often online lessons in my current

setting are simply reading and then answering multiple choice questions. Lessons in the Cycles in the Sky unit seek to increase student engagement by incorporating inquiry and meaningful examples. Each lesson starts with a warm up section that both gauges prior knowledge and allows students to draw connections between their own lives and the lessons. Next, the explore section allows students to use differentiated resources to construct answers to questions. Students explore the “why” behind phenomena rather than simply being tasked with retrieving trivia for assessments.

Summary

In this chapter, I reflected on the development of my capstone project. I explored the resources from the literature review that most profoundly impacted the development of my project and expounded on the lessons I learned as a researcher and creator. Then I explored the policy implications of my project’s development such as the need for introducing Indigenous science knowledge into teacher preparation programs. A discussion of the project's limitations–namely that it is designed for the online setting and incorporates a wealth of examples from Minnesota–followed along with areas for future research. Finally, I discussed how the project could be applied across various settings and the benefits that it provides to the field of astronomy education.

My hope is that this unit gives learners a new way of seeing the night sky. While the stars may be distant, the stories they tell weave us together. Each new name for a constellation provides another way of seeing the world. Taking the time to unravel this rich celestial tapestry connects us to the star gazers who came before and each other.

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