“ENERGY IS…LIFE”: MEANING MAKING THROUGH DIALOGUE IN A TRIBAL COLLEGE PHYSICS COURSE

by

Jessica Christel Antonellis

A Dissertation Submitted to the Faculty of the

DEPARTMENT OF TEACHING, LEARNING AND SOCIOCULTURAL STUDIES

In Partial Fulfillment of the Requirements
For the Degree of

DOCTOR OF PHILOSOPHY

WITH A MAJOR IN TEACHING AND TEACHER EDUCATION

In the Graduate College

THE UNIVERSITY OF ARIZONA

2 0 1 3

THE UNIVERSITY OF ARIZONA
GRADUATE COLLEGE

As members of the Dissertation Committee, we certify that we have read the dissertation prepared by Jessie Antonellis, titled "Energy is…life": Meaning making through dialogue in a tribal college physics course, and recommend that it be accepted as fulfilling the dissertation requirement for the Degree of Doctor of Philosophy.

____ Date: July 19th, 2013
Alberto Arenas

____ Date: July 19th, 2013
Walter Doyle

____ Date: July 19th, 2013
K. Tsianina Lomawaima

____ Date: July 19th, 2013
Deborah Levine-Donnerstein

Final approval and acceptance of this dissertation is contingent upon the candidate's submission of the final copies of the dissertation to the Graduate College.

I hereby certify that I have read this dissertation prepared under my direction and recommend that it be accepted as fulfilling the dissertation requirement.

____ Date: July 19th, 2013
Dissertation Director: Alberto Arenas

____ Date: July 19th, 2013
Dissertation Director: Walter Doyle

STATEMENT BY AUTHOR

This dissertation has been submitted in partial fulfillment of the requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this dissertation are allowable without special permission, provided that an accurate acknowledgement of the source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the copyright holder.

SIGNED: Jessica Christel Antonellis

ACKNOWLEDGEMENTS

Although the giving of thanks may never quite end, it begins with sincere gratitude to the physics students, members of the Student Development Team, staff and faculty of Tohono O’odham Community College, and all contributors to this research, who honored me with their insights and without whom this project would never have come to be.

Huge thanks to all my committee members, past and present, whose support and guidance shaped this ball of wax into something more like the candle it was supposed to be: Alberto Arenas, Walter Doyle, Deborah Levine-Donnerstein, and K. Tsianina Lomawaima, the most passionate yet patient dissertation committee in the world; Leisy Wyman, Bruce Johnson, Richard Ruiz, Tim Slater, Mary Jo Tippeconnic Fox, and Robert Martin, former committee members at previous steps along the way, all of them essential and foundational for my development as a scholar.

Honor and blessings to all the teachers, faculty members and colleagues who lent inspiration and support on this journey: Gina Brissenden, Deb Colodner, Tom Fleming, Karen Francis-Begay, Katy Garmany, Chris Impey, Juana Jose, Serena Kim, Meredith Kupinski, Jane Latané, Danny Lopez, Terry Matsunaga, Abra McAndrew, Phillip Miguel, Cherilynn Morrow, Teresa Newberry, Joy Nichols, Ingrid Novodvorsky, Melissa Ousley, Steve Pompea, Steve Powers, Ed Prather, Brigid Quinn, Mike Renning, April Ritchie, Paul Robertson, Daniella Scalice, Rob Sparks, Olivia Vanegas-Funcheon, Melissa Vito, Connie Walker, Linda Webb, as well as the Tohono O’odham Community College Research, Curriculum and Himdag Committees; the CAPER team; the faculty and staff of the University of Arizona Teaching and Teacher Education, Physics, Planetary Science and Astronomy Departments; the University of Arizona Dean of Students Office, Flandrau Science Center, and Native American Student Affairs; the National Optical Astronomy Observatory; the Collaboration of Astronomy Teaching Scholars; the entire NAALA family; and my colleagues at Little Priest Tribal College.

Without an amazing collection of friends who teach and research, but more importantly who advocate for each other, share their knowledge, commiserate in the dark and bright times, and celebrate every milestone together, grad school would be a dismal experience indeed: Adrienne, Andy, Athena, Audra, Christy, Claire, Delphine, Elisabeth, Erik, Erika, Erin, Gary, Jake, Jamie, Janelle, Jennifer, John, LaKeisha, Lauren, Leland, LeMoine, Lynn, Marilyne, Mascha, Matthew, Nancy, Pebble, Sanlyn, Sofia, Stephanie, and Z, along with all the spouses who graciously let them grab a drink from time to time, or who came along for the ride. And all my friends on the outside who remind me that life goes on beyond the pearly gates: Albert, Angela, Angie, Ann, Anna, Ashleigh, Candace, Dana, Emily, Gisela, Janyce, Jody, Karina, Katie, Kathleen, Keith, Leslie, Lydia, Meredith, Mike, Rachel, Richelle, and Vinsee. Big thanks and hugs to all my compatriots for the laughter, love and light.

I am profoundly grateful for all my families, whether we be bound by biology, law, love or shared joy: Antonellis, Koson, Carter, Sacra, Ciavarra, Smucker, Adent, Cedrone, Lorenz, Curran, Biedrzycki, Migliozzi, John, Yazzie, LaPointe, Long, and Lincoln. And especially to my second sister Erin Dokter, not only for her edits but also her enthusiasm and her faith, without which I could not have moved forward. Lastly but not leastly, Dennita John, thank you for undertaking the arduous task of learning how to be the hands that hold up and hold together a metamorphosing graduate student/scholar.

Named or not, everyone in my life has played a role in bringing this work to fruition. To all my supporters and cheerleaders who recognized, and encouraged me to remember, that a dissertation is a labor of love, in honor of our participants and all who contributed to bringing it to life – thank you.

DEDICATION

For my parents and grandparents,
Gerard P. Antonellis Jr. and Sally Antonellis,
Gerard P. Antonellis, Sr., Jean Antonellis, Walter Koson, and Judith Koson,
the best team of superheroes a girl could ever ask for,
who provided the roadmap for a worthy life
and gave me the moral compass to navigate it;

and for Dennita John,
my tirelessly supportive and endlessly inspiring future wife,
who washed way more than her fair share of dishes
during the writing of this lengthy tome.

TABLE OF CONTENTS

ABSTRACT

This research is an exploration of students' meaning making around physical concepts through connections to students' funds of knowledge. This qualitative case study, influenced by Indigenous methodologies, focused on two Native students in a tribal college introductory physics course, exploring the personal, cultural, and philosophical connections that were voiced in dialogic interactions among the students and instructor.

The data were collected through audio recordings of class sessions and reflective journaling by the instructor/researcher. Analysis identified dialogues in which meaning making took place, and the funds of knowledge that students brought to bear on these dialogues. The results of the analysis of these meaning-making occasions are presented by physical concept.

For both students, the cultural connections they brought in were ways for them to incorporate their out-of-class identities and to consider their cultures from a scientific perspective. The influence of the students' personal connections was just as important as that of the cultural connections; the shared classroom context was also a valuable resource in the for collaborative meaning making. Both students both enjoyed examining the philosophical and spiritual implications of physical ideas; these dialogues provided windows into students' thinking that would not have been accessible in other ways. The students also made meanings about the nature of science that meshed with their identities and created a space for them to identify as scientists, and both came to view science as part of their cultural heritage.

Allowing students free reign to make connections and empowering them to make decisions about their own learning were means of encouraging students to develop meaningful conceptual understanding. By investigating the meanings students made around physical content, we can learn about what motivates them, what is important to them, and potentially how to structure curricula that will better support their meaning making in other courses.

CHAPTER 1: INTRODUCTION

Purpose of the study

Members of diverse classrooms attempt to speak to each other across a space of cultural difference. In the sciences this space can expand threateningly, until teacher and student are marooned and unable to communicate. Opening up the classroom to student voice and building discourse upon contexts shared by different groups of people in the class is a way to reach across this distance with bridges that link both shared and diverse perspectives. This case study of an introductory physics classroom at a tribal college investigates the process of constructing these bridges to develop a third space shared by Native American college students and their non-Native instructor, as well as the ways in which the discourse that emerged from this third space contributed to students' meaning making with the content.

> It is, exactly as I intended, [a] student-driven creation of connections between something (physics) that is usually perceived as dry, highly-technical and abstract, and impersonal, and something that is highly personal, deeply conceptual and meaningful…

This quote is taken from my reflections on a particular class session, late in the semester, from the culturally-relevant physics course I developed and taught for Tohono O'odham Community College. This selection represents the moment when I realized that something important and exciting was happening in the students' dialogues – something I had not anticipated, but which was a direct outcome of the decisions I had made in creating an environment that welcomed cultural perspectives. It was on this day that the research described in this dissertation began unfolding, when I discovered that "student voice" in the classroom was more than just students' responses to teacher-directed questions, and more even than simply the inclusion of student input on course decisions. Student voice was the manifestation of students' agency and power in the classroom setting, and the students utilized this voice to co-create meaning and understandings from their science learning that went far beyond what their naïve young teacher had intended for them.

Background

Over the last several decades, Native Americans have made great strides in increasing their representation in the field of science. Thousands of Native students graduate with undergraduate degrees in science, technology, engineering and mathematics each year, hundreds obtain advanced degrees, and these numbers continue to climb every year (National Science Board, 2010). There are Native scientists in the fields of neuroscience, chemistry, environmental studies, geology, and many others (Vélez, SACNAS Biography Project). Through the efforts of such organizations as the Society for Advancement of Chicanos and Native Americans in Science (SACNAS) and the American Indian Science and Engineering Society (AISES), more Native students have begun to see science as a career option.

However, most students, both Native and non-Native, do not pursue professional careers in science. For some students, the perception of science as too difficult and the lack of role models and support in science are sufficient to discourage their interest in science as a career (Aschbacher, Li & Roth, 2010). For Native American students, additional factors are the disconnect between classroom science and students' home culture (Aikenhead, 1996) and the lack of perceived relevance to students' lives. Native students face additional challenges; a higher percentage of students in rural, low-income areas results in unequal access to quality math and science education (Babco, 2005), and Native students often face a perceived need to abandon cultural beliefs and values in order to embrace a scientific mindset (Gates, 2006). Avoiding science can be the reason why some Native students do not finish their post-secondary education (Cajete, 2010), never mind going on to become scientists.

Yet there are numerous scientific issues facing tribal communities, from developing alternative energy sources to ensuring clean drinking water, from managing wildlife resources to dealing with climate change. Wilma Mankiller, former principal chief of the Cherokee Nation, stated that tribal communities simply do better when they manage their own affairs (2008). Thus, Native communities need their own scientists, who understand not only the underlying mechanisms affecting the tribal landscape but also the cultural considerations of the people. Likewise, community members must themselves be aware of the relevant scientific concepts in order to understand how their day-to-day activities may interact with larger issues facing the community. Finding culturally-appropriate solutions to the scientific issues that face tribal communities requires local experts and a scientifically literate populace, both of which demand increased access to relevant, high-quality science education for tribal communities (James, 2001b).

Mainstream science education, highlighting the scientific tradition of the dominant Western culture, is not well-suited to the needs of Native students. Kawagley and Barnhardt (1998) criticized the way that education so often presents students with a great deal of information but does not prepare them to live fulfilling lives. Students from outside the dominant culture often find it difficult to relate to Western science because it is so dissimilar from their own cultures' means of understanding the world (Cajete, 1999a).

As with all human communities, Native communities have processes through which they gather and organize knowledge about the world around them (Cajete, 1999a; Lambert, 2003). Like Western science, Native science "consists of a set of explanations which seek to make sense of the natural world and which are consistent with a particular worldview" (Baker, 1996, p. 19). For Native communities, science is also a philosophy that explores the spiritual connections between humans and all life (Cajete, 2000).

This research represents an effort to encourage Native students to bring their cultural values and perspectives to bear on their science learning. Science curricula built within critical pedagogy and focused on personal and cultural relevance encourage Native students to see that scientific knowledge is a part of their heritage and can be used to address their community's needs. Should students be inspired to pursue further study in the sciences, having viewed science through a cultural lens early in their post-secondary careers will provide them with a foundation for continuing to make connections between academics and their home culture in mainstream institutions, where such connections are not explicitly nurtured. Further, should these students go on to become professional scientists, their knowledge of science, grounded in the worldview of their community and inclusive of its traditional knowledge, will afford them perspectives of their field that may be unique in all the world.

Setting of the study

The tribal college environment is especially suited for developing and implementing culturally-relevant science curricula. The now nearly 40 tribal colleges across the United States are locally-controlled, autonomous institutions whose collective mission is to serve their particular tribal communities. The goals of tribal colleges include responding to community needs, empowering communities, and preserving and revitalizing Native culture and language (Pavel, Inglebret & Banks, 2001) – each a goal with which culturally-relevant pedagogy is aligned. Tribal colleges "sit at the fulcrum between the Indian and non-Indian world" (Boyer, 1997, p. 25), preparing students to both succeed in the modern Western society and to meaningfully participate in tribal traditions. Developing culturally-integrated curricula at tribal colleges is a possibility, due to their autonomy from the standards and practices of mainstream schooling, and also a priority, for the sake of providing students with the best educational experience available and developing future leaders who can address communities' difficult challenges (Johnson, Benham & Van Alstine, 2002).

This research took place at Tohono O'odham Community College (TOCC), a tribally-controlled college chartered by the Tohono O'odham (formerly Papago) Nation located in southwestern Arizona. Chartered in 1998, the College began offering classes in 2001 (Tohono O'odham Community College, 2010), and merged in 2001 with the existing Tohono O'odham Career Center (formerly the Papago Skill Center), a vocational training center established in 1979 as an alternative to the off-reservation training that was previously the only option available to O'odham students (Grater & Antonellis, in press). The college offers developmental programming, employment certificates, and two-year degrees. TOCC's mission is "to enhance the unique Tohono O'odham *Himdag* by strengthening individuals, families, and communities through holistic, quality higher education services" (Tohono O'odham Community College, 2010). The *Himdag* is that which defines an O'odham collective identity, encompassing the O'odham culture, language, value system, and way of life (Tohono O'odham Community College, 2002).

Theoretical framework

This research is grounded in two main theories: sociocultural theory and hybridity theory, which contextualize the need for a culturally relevant pedagogy. Sociocultural theories focus on the influence of students' cultures on their learning, thinking, and communication styles and values (Vygotsky, 1981; Banks, 1994; Nieto, 1998; Winzer & Mazurek, 1998; Gay, 2000). "Socio-cultural theories assume that making the curriculum and the classroom processes compatible with the cultures of the students will produce a higher rate of academic achievement and school success for those students whose home cultures would otherwise conflict with those of the school" (Kanu, 2006, p. 121). This ideology is present in Demmert and Towner's (2003) cultural compatibility theory, which posits that "education is more efficacious when there is an increase in congruence between social cultural dispositions of students and social cultural expectations of the school" (p. 7). Through a sociocultural lens, a science classroom is a subculture, "with particular ways of knowing, talking, and doing that do not always clearly align with the social worlds that youth bring to learning science" (Calabrese Barton, Tan & Rivet, 2008, p. 72).

Moje et al. (2004) drew upon hybridity theory (Bhabha, 1994; Soja, 1996), which posits that "people in any given community draw on multiple resources or funds to make sense of the world" (p. 42). Gutiérrez, Baquedano-López, and Tejada (1999a) defined hybridity as a multitude of voices, perspectives, and context – a diversity of identities, backgrounds, and approaches (Discursive tools). Calabrese Barton, Tan and Rivet (2008) drew upon the hybridity lens to interpret "youth taking up knowledges, resources, and identities in novel ways that often go unsanctioned by school science…This allows them to build their social identities while they build and gain epistemic authority in the classroom" (p. 74).

Hybridity theory also investigates how being between different resources or funds – i.e., being in the third space – can be productive (leading to growth in knowledge or identity) or constraining (restricting change). Moje et al. (2004) viewed the third space as full of potential, where "what seem to be oppositional categories can actually work together to generate new knowledges, new Discourses, and new forms of literacy" (p. 42) – all hybrids of the knowledges, Discourses and literacy that were drawn into the third space. "Although we agree that all moves to make sense of the world construct hybridity at some level, our view of third space suggests that such hybridity could be brought into the open to resituate often marginalized experiences and to develop conversations about the relative value of scientific, abstracted knowledges, vis-à-vis personal, experienced knowledges" (p. 57).

In this work, I distinguish between hybridity, hybrid understandings, and third space. My usage of the term hybridity refers to the condition of a setting, such as a classroom, in which diverse perspectives and funds of knowledge are present within and among the different participants. Such perspectives and funds can be brought into the third space, which I define as the metaphorical space where different ideas are shared, explored, and negotiated – this interaction of perspectives in the third space is distinct from its mere presence as a condition of a group setting. In the classroom context, the third space includes ideas about academic content along with students' and instructors' existing funds of knowledge. My conceptualization of third space follows from Gutiérrez, Rymes & Larson (1995), who wrote of third space as the place where the teacher (academic) and student worlds merge and share power, and Moje et al. (2004) as the space where different Discourses come together.

Hybridity in the third space creates the potential for developing hybrid understandings that are influenced by different perspectives, yet which are new and unique negotiations of the multiple perspectives. Hybrid understandings are created by a collective of people who position themselves differently and distinctively relative to each other, yet who share power and agency in the third space. In the classroom setting, hybrid understandings of the classroom content are specific to the participants of the class, and draw upon academic, personal and cultural interpretations.

Following from hybridity theory, culturally relevant pedagogy as defined by Belgarde, Mitchell and Arquero (2002) emphasizes the students' role in the co-creation of knowledge through the making of connections between the content and their cultural backgrounds, which leads to student empowerment and collaboration with the instructor (Reyhner, 1992). As will be further elucidated in Chapter 2, different scholars use different words to describe this concept (e.g. “instructional congruence”, “cultural responsiveness”), and understand it in different ways (e.g. as something the student does versus something the instructor does). The idea of cultural relevance as a pedagogical approach puts the responsibility for drawing in these connections upon the instructor, however the students play a significant role as well: it may be students who suggest possible connections between classroom content and their funds of knowledge, and thus the instructor’s responsibility is to honor and validate those connections. There is an overlap between cultural relevance and adult learning theory (Knowles, 1973), which emphasizes personal relevance, in that the connections that students or instructors make may come from personal or cultural funds of knowledge, or some blend of the two.

Use of “Native” and “Indigenous”

An explanation of why and when I chose to use these terms out of the many commonly used to describe Native people (e.g. Native American, American Indian, First Nations, First Peoples) is in order. Throughout the bulk of this document, I commonly use the term “Native” as an adjective that refers to individuals who identify as Native American. In my everyday parlance, such as during the teaching of the course, my preference has been for this linguistic shorthand when speaking of the collective of Native peoples in the Americas, though I use specific tribal adjectives (e.g. “O’odham”, “Navajo”) when specificity is more appropriate. In so doing, I am following the lead of such authors as Nelson-Barber and Estrin (1995b) and Cajete (1999a), who use the term "Native students", as I do throughout this document.

The word "Indigenous" has a slightly different implication, as it is inclusive not only of tribal peoples of the Americas but of first peoples across the globe. As Wilson (2008) explained, "Indigenous is inclusive of all first people – unique in our own cultures – but common in our experiences of colonialism and our understanding of the world" (p. 16). Smith (2005) offered a related definition: "Indigenous people can be defined as the assembly of those who have witnessed, been excluded from, and have survived modernity and imperialism" (p. 86). The term "Indigenous" has political implications; "in the face of colonization we [Indigenous peoples] assert our collective rights as self-determining peoples at an international level" (Wilson, 2008, p. 34). I follow Wilson's and Smith's lead in using the term "Indigenous" to speak more broadly of first peoples as an increasingly influential political entity. I use this term to refer to Indigenous methodologies, for instance, as this approach to research is emerging world-wide from communities of Indigenous scholars.

Rationale for the study

This inquiry into meaning making in the "third space", a conceptual space between academic and everyday Discourses, in the tribal college science classroom is unique in the literature. It may be informative for educators looking for a window into tribal college students' thinking as they learn science, and those seeking to support that learning rather than to impose the replacement of cultural knowledge with content knowledge. When these efforts are successful, they can support students' success in science by building upon rather than compromising their identities.

Research question

This research was intended as an exploration of the meaning making through connections to students' funds of knowledge in a tribal college science classroom. The research question guiding the study follows directly from this purpose:

> Within the context of a physics course designed to be culturally relevant, how did students make meaning of physical concepts through dialogue?

This question was explored with a qualitative methodology influenced by Indigenous methodologies, focused on the dialogic interactions among the students, instructor, and other participants in the classroom. This methodology will be described in further detail in Chapter 3.

Outline of the dissertation

In Chapter 1, I have summarized the study and provided the theoretical framework that underlies its development and the analysis of results. In Chapter 2, I discuss relevant literature and studies that resulted in a conceptual theoretical framework for the study and the course developed as the setting for the study. In Chapter 3, I tell the story of the study, through its initial conception through its metamorphosis into its final form. This chapter also includes a description of the course, from its development to its implementation. In Chapter 4, I summarize the findings from the research, and in Chapter 5, I discuss the implications and significance of the findings.

CHAPTER 2: REVIEW OF THE LITERATURE

Overview

"Getting to know something is an adventure in how to account for a great many things that you encounter in as simple and elegant a way as possible" (Bruner, 1996, p. 115).

This chapter represents the process of "getting to know" the network of knowledge that underscores the creation and implementation of this research project, consisting of theoretical and research literature about student meaning making from the perspectives of cultural relevance, border crossing, and discourse theory. As my rather intelligent brother (Antonellis, 2011) posited, "There is an archaic ideology which is still espoused that insists on viewing and coddling originality as if it were a unique singularity born of spontaneous generation and not built on the shoulders of the amassed knowledge. Originality is the successful addition to a cumulative process, building off of what was there before" (p. 29). My brother also invoked what he called "time traveling bandits" that took his thoughts to the past where they were fine-tuned and expanded upon, only to be rediscovered by him later. I can relate to that experience of recognition upon seeing my own thoughts reflected in the works of others.

This chapter summarizes the literature that sheds light upon my study. In reviewing this literature to inform my data analysis, I saw many of my own thoughts and sentiments about education for Native students being echoed. Working in this field, I am standing on the shoulders of the same giants and have been deeply influenced by them – giants such as Dewey, Ladson-Billings and Villegas in cultural relevance; Cajete, Kawagley and Barnhardt in culturally-relevant science education for Native students;

Aikenhead and Jegede in border crossing; Veléz-Ibañez, Greenberg and Moll in funds of knowledge; and Bhabha, Gutiérrez and Moje in hybridity and third space. These works form a foundation upon which later researchers (e.g. Nieto, 1998 and Gay, 2000; Apthorp, D’Amato and Richardson, 2002 and Belgarde, Mitchell and Arquero, 2002), including myself, have built, and the theories developed by the ground-breakers in the field are reflected in these later works. Indeed, this original dissertation owes everything to the scholars and thinkers who came before me; what follows is an account of all these influences, in as simple and elegant a way as I could muster.

Education as cultural

Like all human enterprises, teaching is embedded within a cultural context and is itself a cultural activity. Students assign meanings to perceptual experiences in both personally and culturally defined ways, and the task of instructors is to be cognizant of how students assign meanings and how those meanings affect their thinking (Agbo, 2001). This is true for all students, and it is true for the instructor as well: in the same manner that Native students acquire learning styles in part from how they are taught within their cultures, White teachers and students acquire their learning styles and, related to this, their teaching styles. The culture of the classroom is borne of child-rearing practices in the dominant society; White children are typically not expected to participate in the activities of adults, because those activities are frequently exclusive to children (Kaulback, 1997). Communication instead centers on questioning and explaining. This style of verbal interaction naturally became the dominant means of instruction in schools, though it is not necessarily aligned with the communication styles that students from other cultures experience at home.

Swisher and Deyhle (1992) wrote about how verbal communication-centric teaching “conflicts with the traditional cultural patterns reinforced in many Indian communities, where visual perception is encouraged” (p. 92). Ongtooguk (2000) described how the traditional Iñupiat child, for example, would engage in increasingly sophisticated observations of a process, eventually coming to understand the principles by which the process was enacted (for example, what must be known in order to load a properly balanced boat). Iñupiat children would also learn from repeated tellings of stories, through which important practical and moral information was conveyed. Later, young people received on-the-job training through apprenticeships that accentuated the importance of the roles they would fulfill as adults.

Instructors may consider their practices to be culturally-neutral, though what instructors from the dominant culture consider to be “culturally-neutral” tend, in actuality, to privilege those students who are from similar cultures to the instructor and disadvantage those who are not. Students can experience cultural discontinuity when their values conflict with the values promoted by the school. An instructor who is not aware of how cultural differences influence teaching and learning is ignoring the needs of students (Johnson, 2003); “Cultural differences are noted but seldom viewed [by non-Native teachers] as valid or valuable to the student and essential to both cognitive and social development” (p. 192). When [the] students’ home culture is not valued nor represented, they are walking into a whole new world when they cross through school doors (Agbo, 2001).

Thus, gaining an awareness of the students' cultures is essential for instructors' ability to be responsive to their students' needs and promote meaning making in their classrooms. Reflecting the home culture in the classroom promotes students' learning (Martin, 1997). When teachers are respectful of and open to their students, they help students come to value their learning, as well as their own cultural identities (Agbo, 2001).

Research on Native students' learning styles

One of the first things that instructors can do to help gain an understanding of their students is to obtain a general sense of their learning styles. Learning style generalizations provide an over-simplified picture of students – learning style research may in fact be used to support racism rather than multicultural understanding (Chrisjohn & Peters, 1986) – so it is merely a first step. Good sources for this kind of information are Gilliland's (1999) *Teaching the Native American* and Cleary and Peacock's (1998) *Collected Wisdom*. *Teaching the Native American* is a book of practical knowledge for teachers of Native American students, from promoting students' positive self-image to involving parents in their children's education; from teaching to students' learning styles to incorporating language and culture into the curriculum. Gilliland's book is designed to be a tool for educators to help them make their classrooms and their practice welcoming and nurturing toward Native students. It is important to note that Darby (2000), while overall praising the work, warns educators that Gilliland takes a more assimilative than transformative approach, and that his generalizations run the risk of creating a monolithic Native student. As well, while Gilliland's advice may apply to adult learners, it is primarily concerned with children.

Although Native students are no longer considered to have a singular learning style (Cajete, 1999b), there are some similarities in approaches to learning that some Native students may share, which "are mediated by their particular cultural orientation" (p. 155). Cajete (1999a) offered what he found to be the common characteristics of his students over the course of his teaching (p. 19). These students:

- *Tend to learn best that which is related to a familiar set of descriptive relationships.* This idea is attuned to constructivism – that students learn best when they can relate new information to their existing knowledge – but based on the interactions between ideas rather than self-standing ideas. It might not be as useful to a Native student to think of phylogeny as a tree with a trunk and big and small branches, as to think of it as a family lineage with groups that are connected but related more or less distantly.
- *Prefer to learn in high-context interactional working situations*. Native students, according to Cajete, make meaning of information more readily when it is presented within the context of the variables that affect it, as opposed to decontextualized learning such as reading and lecture that pull out pieces of a system for examination rather than looking at the system as a whole.
- *Prefer loosely structured and informal settings for learning*. Unlike some teachers and students who work best with routine and structure, Cajete's students preferred

a less rigid, more experiential format for learning that allows it to take place naturalistically and allows students to make connections on the fly.

- *Exhibit an overall whole-brain orientation in the processing of information.* Rather than a "file folder" approach, where certain information is mentally stored under certain "headings", Native students' mental maps may look more circular, with knowledge fitted into systems and processes with recognition of the interdependencies between them. It is a different way of approaching learning – holistically, seeing both the beginning and the end and the steps in between, and attaching personally-defined meanings to relationships between concepts, instead of a strictly linear progression.
- *Exhibit highly visual, spatial and kinesthetic orientations, and think in images rather than words.* While schooling tends to emphasize the linguistic/mathematical modalities of learning, Native learners tend toward more visual and kinesthetic learning. This is not to say, of course, that Native students should be expected to only learn through their sense of sight, but rather that the use of visual aids might be a good place to start in a multimedia lesson.
- *Have an oral as opposed to a written language orientation.* This characteristic has implications for the way Native students perform on assessments. Assessments that rely heavily on writing may not capture all that Native students understand about a concept; multiple forms of assessment are probably more appropriate. The oral orientation may also affect students' writing style; it may be more

conversational than academic, as Brandt (2008a) saw in her study of Navajo science majors.

Collected Wisdom (Cleary & Peacock, 1998) is a guide for teachers of Native students, but told through the collected stories, thematically arranged, of experienced educators. It discusses cultural differences between teachers and students, the effects of generations of oppression on students, being bicultural, Native languages, ways of learning, ways of thinking, and motivation. It is much more appropriately applied to adult learners, and contains such useful (and carefully non-specific) descriptions of learners such as this (p. 172):

- Some American Indian students may be visual learners who learn best through observation.
- Some American Indian students may need to feel competent in an activity before they will engage in it.
- Some American Indian students may learn best in cooperative rather than competitive environments.
- Some American Indian students learn best from practical and personal application and stories.
- Some American Indian students are wholistic, creative learners.

The purpose of the careful phrasing and avoidance of generalizations on the part of Cajete and Cleary and Peacock was to emphasize the diversity of characteristics, true for any population of students. Teachers are encouraged to learn about their students and to tailor their pedagogical approaches to their specific students' needs.

Research on American Indian students in higher education

In reviewing the literature on American Indian college students, Brandt (2008b) found primarily quantitative studies that tended to focus on student "failure" rather than success. I similarly found many studies pertaining to the retention/persistence of Native students in college, including qualitative studies investigating the characteristics of students who succeed in higher education. What follows is a synopsis of the research on American Indian college students' success in the college environment.

Characteristics of Students

Despite earlier research indicating that Native students who identified with White students were more academically successful (Kerbo, 1981), many researchers have found that Native students who come from more traditional families are more likely to be academically successful in higher education than their more acculturated counterparts (Barnhardt, 1994; Belgarde, 1992; Belgarde & LoRé, 2003-2004; Hobson, 1994; Huffman, Sill & Brokenleg, 1986; James, 1981; Kirkness & Barnhardt, 1991; LaFramboise, 1988; Lin, 1990; Lin, LaCounte & Eder, 1988; LoRé, 1998; Rindone, 1988; Willeto, 1999; Wright, 1992; Wright & Tierney, 1991). The explanations suggested by the literature for this phenomenon are two-fold. On the one hand, students who are well-versed in their traditional cultures have strong self-identities as well as high levels of support and encouragement from their communities, both promoting their academic success (James, 1981; Barnhardt & LoRé, 2003-2004). On the other hand, students who have grown up with a very traditional home life are likely to have crossed borders consistently throughout their early education as well as in other interactions with the outside world. These experiences provide students with skills in navigating the multicultural world, skills that stand students in good stead when they enter the post-secondary environment (LaFramboise, 1988). In combination, the positive self-image and confidence, support from community, and border-crossing skills may provide a competitive edge for traditional students as compared to Native students with less of a community connection.

Aragon (2002) surveyed over 200 Native community college students in the Southwest about the factors that influenced their motivation in the classroom. Aragon found that students preferred teacher-centered over student-centered classrooms, but within teacher-centered settings they favored having opportunities to engage with the instructor and the classroom activities. The researcher also learned that the students tended to believe that they were in competition with other students in the classroom for rewards such as grades, feedback from the instructor, and recognition. More student-centered settings were favorable when they included opportunities for the students to interact and collaborate, and for students to self-pace. Other motivating factors were independent learning, ability to influence the direction the course and curriculum take, and ability to learn by doing.

Benjamin, Chambers and Reiterman (1993) also studied Native students in the Southwest, but in the university setting (n=166; students were freshman in 1984 and 1985). Among this cohort of students, only 16% (26 students) had graduated after six years. However, the researchers' emphasis was on the ones who *did* succeed, which the researchers referred to as "the persisters". Like the students in the larger student body, the persisters tended to be those who entered college as traditional-age students, those who had ranked higher in their high school classes, those with higher ACT scores, and those with higher GPAs during their college years. However, these relationships were not as strong in the American Indian sample than in the larger student body. Higher achieving and lower achieving students were similarly likely to persist to graduation. There was little predictability of ACT scores or high school rank; the researchers concluded there was some other factor not being accounted for. They interviewed 11 persisters from the original cohort in 1988 and 1989 (all Navajo despite efforts to have different tribes represented). The persisters reported frequent trips home as a positive motivator for them, because they received encouragement from their families and were reminded about why they were in college. This result corroborates Rindone's (1988) finding that parental influence was a strong motivator of Navajo college students and contributed to their success. All of the persisters had set their minds on college from an early age, and expressed beliefs that students who decided to go to college later, such as in their last year of high school or after graduation, were more likely to fail because they had not been preparing themselves during their pre-college years. The students all placed themselves in the middle of a continuum between traditional (in this case, traditional Navajo) and White, leaning toward the White. By contrast, all placed their friends from home close to the "traditional" end, suggesting that they perceived themselves to have adapted, adopting some characteristics of a stereotypical White person to succeed in college.

The Role of Faculty Interactions

Instructors have been found to exercise a strong influence on Native college students' retention and satisfaction with their college experience (Cole & Denzine, 2002; Dodd, Garcia, Meccage, & Nelson, 1995; Reyhner & Dodd, 1995). Even students who reported low satisfaction with the campus climate tended to be largely positive toward their instructors (Huffman, 2001; Lin, LaCounte, & Eder, 1988; Tate & Schwartz, 1993). Likewise, the caring, warmth, and accessibility of faculty members were cited as essential for student success by Native students at the University of Alaska-Fairbanks in Wilson's (1997) study.

Brown and Robinson Kurpius (1997) found that Native college students' success was dependent upon their academic and social integration into campus life; in addition to academics, interactions with faculty and staff members were also critical for students' persistence. HeavyRunner and DeCelles (2002) argued that family-like relationships between faculty members and students contribute to student persistence because students feel a greater sense of belonging.

Teacher attitude, including enthusiasm, care for students' needs, encouragement, availability, and willingness to develop personal relationships with students, was the most influential factor for student success in Schmidtke's (2009) qualitative (interview-based) study of Native students at South Central Institute of Technology. "Instructors' greatest impact lies in areas of cultural sensitivity, academic and personal relationships, instructional methods and design, and sensitivity to student learning styles" (p. 51). Schmidtke found that being part of a community was important to the students, so in addition to building relationships with instructors, another factor that contributed to the students' success was collaborative learning. Also beneficial were hands-on learning, the ability to self-direct their learning, guidance on how to solve problems, demonstrations rather than explanations of how to use a new skill, and individual attention when they needed help.

Teachers' involvement in the community of their students has several positive effects. If teachers take the initiative to hear the aspirations that families have for their children, even their adult children, and talk with families about the teacher's hopes for the class, teachers can build a reciprocal relationship with the family members. Rather than harboring negative feelings about schooling and passing these attitudes to their children, families have a vested interest in their children's education and are able to exchange information with the teacher (Reyhner & Jacobs, 2002). This is, of course, an idealized situation, and change is slow, but efforts on the part of the teacher to become involved are crucial. Teachers need to allow community members' voices to be heard and make attempts to increase community participation (Agbo, 2001).

Relationships in the classroom

According to Nelson-Barber and Estrin (1995a), "Using [connections] from students' lives will not compensate for lack of a real relationship between teacher and student. Reliance on method or content alone is an inadequate strategy" (Nelson-Barber & Estrin, 1995a, p. 183). Although it is important to gain an understanding of the general traits of one's students, the best advice for teachers who are interested in connecting their teaching to their students' experiences is to first venture out into the community. Rather than relying on others' impressions, anecdotally or in writing, it is better to immerse yourself in the culture without preconceptions. Becoming involved in the community before starting a teaching experience provides community members with a chance to know an instructor as a person instead of just as a teacher. Barnhardt (2000) advised instructors to keep an open mind and make an effort to understand people and their ways before judgment.

Venturing out into the community also helps foster relationships with elders, who may possess traditional knowledge that students are (ideally) taught outside of the school setting. In traditional Native societies, all members were charged with and trained to be teachers, and elders in particular were responsible for "governing the process of sharing knowledge" (Pavel, Inglebret & Banks, 2001, p. 52). Teachers who are respectful of the role of elders may find a source of cultural connections to bring into the classroom.

According to Patchen and Cox-Petersen (2008), "Extending beyond the classroom to the outside depends upon teachers and students developing real relationships, based upon mutual understanding and exposure to different perspectives" (p. 1007). Becoming involved in the community sends the message that the teacher cares enough about his or her students to want to know about their lives, and gaining access to community funds of knowledge provides opportunities for educators and students to create connections across the curriculum.

Culturally-Relevant Pedagogy

The sections that follow review perspectives on meaning making from the framework of culturally-relevant pedagogy. In culturally-relevant pedagogies, students are supported in developing meanings that resonate with their personal and cultural identities.

The Need for Culturally-Relevant Pedagogy

The tragedy of mainstream education for Native students is that it often forces them to choose between maintaining the integrity of their cultural traditions and succeeding academically, often in an institution whose goals are set by non-community members. Traditional knowledge is essential for both education and identity formation (Reyhner & Jacobs, 2002), yet school knowledge and traditional knowledge can be at odds, particularly if the latter fails to be acknowledged in the school setting. Monroe (2002) stated that "until both the curriculum and those who teach it 'become more Aboriginal', schools will retain only those Aboriginal students willing to renounce their culture and their communities in favor of a diploma" (p. 552). Native students' self-esteem often depends upon their identification with traditional values (Agbo, 2001). The choice for students who are not able to adapt successfully (as in Gallagher, 2000) is between assimilation and withdrawal; between sacrificing their identities and personal well-being, and sacrificing their education and perhaps future livelihood.

This bleak dichotomous reality need not be the only one. If, as Monroe suggests, schooling can "become more Aboriginal", Native students' educational experiences can support their identities rather than fragmenting them. According to Agbo (2001), the traditional failure of the education system to adequately serve Indigenous students is due to the lack of recognition of Native culture in schools. It is a situation that applies not only to individual students as they progress through their academic careers, but historically to peoples that have experienced oppression through education for hundreds of years. Education that supports students' Native identities is essential for the continued existence of Native communities.

Students achieve better academically and are more balanced emotionally when they are immersed in their own language and culture (Pavel, Inglebret & Banks, 2001). In fact, students who can relate to both mainstream *and* tribal cultures have been found to be more academically successful (Gallagher, 2000; Benjamin, Chambers & Reiterman, 1993; Rindone, 1988). The task for educators, then, is to bring students' languages and cultures into the classroom in a meaningful way. As Nelson-Barber and Estrin (1995a) related, "If meaning is made through connections to 'personal models of reality', then ways must be found to help American Indian students forge those connections" (p. 178; citing Kieren, 1992).

Educational researchers have called such culturally integrated curricula, and other comparable pedagogical initiatives intended to benefit students from minority communities, by different but similar names. The approach that Lee and Fradd (1998) referred to as *instructional congruence* has its analog in what Au and Jordan (1981) called *culturally appropriate* and Mohatt and Erickson (1981) called *culturally congruent*, which is similar to the notion of *culturally responsive* (Cazden & Leggett, 1981; Erickson & Mohatt, 1982) and *culturally compatible* (Jordan, 1985; Vogt, Jordan & Tharp, 1987) curricular approaches, not unlike Irvine's (1990) *cultural synchronization*. In this work, I will echo Gloria Ladson-Billings' (1995a, b) term, *culturally relevant pedagogy*, because her research was foundational for my own. No matter the particular name chosen by researchers and theorists, each would fall under Demmert and Towner's (2003) cultural compatibility theory, which posits "that education is more efficacious when there is an increase in congruence between social cultural dispositions of students and social cultural expectations of the school" (p. 7).

In the field of Native education, efforts by educators to improve the educational experiences available to Native students focus on enhancing the cultural relevance of the curriculum by, for instance, imbedding the context within models of the culture's worldview (e.g., Fenelon & LeBeau, 2006). Culturally-relevant curricula have been found (by studies such as Matthews & Smith, 1994) to promote Native students' academic success by immersing them in their own language and culture (Pavel, Inglebret & Banks, 2001), thus providing students with opportunities to make meaning within familiar contexts.

Tenets of Culturally-Relevant Pedagogy

Factors such as cultural differences between minority students and their primarily White teachers, incongruence between the values and goals of students' communities and the values and goals of the school, and a paternalistic attitude that has systematically silenced minority communities with regard to their children's education, are considered to be major players in the high drop-out rates and low achievement of minority students (Phuntsog, 1998). Culturally relevant schooling is hoped to be a solution for creating equitable, high-quality education for all students. The idea of 'cultural relevance' was introduced in the 1920s by Dewey, who promoted curricula that were relevant to the community in which they were taught, respectful of the community's needs, nonassimilationist, and which encouraged the use of primary languages (Belgarde, Mitchell & Arquero, 2002).

Cultural relevance promotes student meaning making by validating students' languages and cultures and inviting them to co-construct knowledge (Belgarde, Mitchell & Arquero, 2002). "Students become active generators of knowledge, building new academic knowledge by making connections to cultural, community and home-based experiences" (p. 43). Similarly, Allen, Resta and Christal (2002) described cultural relevance as "using the cultural knowledge, prior experiences, frames of reference, and performance styles of ethnically diverse students to make learning encounters more relevant and effective for them" (Allen, Resta & Christal, 2002, page 52). Researchers Apthorp, D'Amato and Richardson (2002) demonstrated that such educational experiences were effective for student learning, reporting that the outcomes of a science camp designed to be culturally relevant were academic gains over a control group and over the treatment group's prior performance, as well as a decrease in school drop-out rates.

Lipka outlined the characteristics of culturally-based education, in this case in mathematics, as used by the Math in a Cultural Context project: "Our definition of culturally based math education includes math content knowledge (informed by both Western knowledge and that of Yup'ik elders), pedagogical knowledge (informed by school-based practices and community-based ways of teaching, communicating, and learning), and contextual knowledge (ways of connecting schooling to students' prior knowledge and the everyday knowledge of the community)" (Lipka, Hogan, Webster, Yanez, Adams, Clark & Lacy, 2005, p. 368).

Villegas (1991) outlined five teacher competencies for culturally responsive pedagogy (p. 23-29):

1. 'Teachers should have an attitude of respect for cultural differences, a belief that all students are capable of learning, and sense of efficacy." Villegas identified this as the attitudinal disposition necessary for effective teachers of diverse students. They must recognize that students' differences are not deviations from the dominant society's norm, nor are they deficiencies to be remedied. Using a constructivist pedagogy, teachers should understand that students' cultural experiences constitute a wealth of knowledge upon which to build. Students' cultural characteristics should not be excuses for why teaching does not work with some students.
2. "Teachers must know the cultural resources their students bring to class, and they must be aware of the culture of their own classrooms." These resources include students' prior experiences, languages, communication and learning styles. Teachers should make an effort to learn about their students through such methods as interacting with their communities, meeting their parents, and listening to students. Teachers should be aware that classrooms and teaching are not culture-neutral, and ensure that the assumptions of the classroom promote rather than extinguish respect for differences. The classroom should reflect the

home culture as much as possible, but teachers should also be cognizant of their own cultural backgrounds and how they influence the classroom culture.

3. “Teachers should implement an enriched curriculum for all students.” All students deserve a challenging curriculum, as opposed to the skills-based, drill and practice-heavy pedagogies to which minority students have often been subjected. Learning should be meaningfully connected to life outside the classroom in order to motivate and engage learners.
4. “Teachers must build bridges between the instructional content, materials and methods, and the cultural backgrounds of the students in their classes.” Teachers must seek to connect classroom learning with students’ backgrounds; students should be able to see themselves in the curriculum and to build from what they know to what they do not. Instructional methods should also reflect students’ backgrounds; for instance, in a culture in which children learn by observation, demonstrations should be a component of the classroom.
5. “Teachers should be aware of cultural differences when evaluating students.” This tends to be the one competency that many teachers resist (Rodriguez & Sjostrom, 1996), possibly because they value a level playing field over any consideration of cultural appropriateness. This resistance may be due to a failure to realize that students may have different norms for displaying knowledge and competence than the teacher does; the teacher’s preferred mode of assessing such knowledge and competence may misrepresent the students’ abilities. Relying on multiple forms

of assessment that allow students to demonstrate competence in different ways is one method for achieving equity in assessment.

Villegas (1988) stated that “culturally sensitive remedies to educational problems of oppressed minorities that *ignore the political aspect of schooling* are doomed to failure” (p. 263; emphasis added). Ladson-Billings’ (1995b) model of culturally relevant pedagogy addressed this political aspect, as it was “designed to problematize teaching and encourage teachers to ask about the nature of the student-teacher relationship, the curriculum, schooling, and society” (p. 483).

Ladson-Billings (1995a) outlined three criteria for culturally-relevant teaching: that it (1) develop students’ academic knowledge and abilities; (2) nurture students’ cultural and academic identities, or what Ladson-Billings referred to as developing *cultural competence*, in which students both “maintain their cultural integrity while succeeding academically (1995b, p. 476); and (3) support students in developing a critical lens toward issues of social injustice, or what Ladson-Billings referred to as being able to both “understand and critique the existing social order (1995b, p. 474).

Ladson-Billings’ focus was on creating the class structure and designing the curriculum to support student outcomes, and Villegas emphasized teacher competencies; both are crucial, as it is the instructor who develops the official curriculum and sets the tone for the learning environment. Culturally relevant pedagogy as defined by Belgarde, Mitchell and Arquero (2002) emphasizes the students’ role in the co-creation of knowledge through the making of connections between the content and their cultural backgrounds, which leads to student empowerment and collaboration with the instructor

(Reyhner, 1992). Thus, if given the opportunity and support to do so, students themselves can help develop and structure the course content so that it both reflects and fosters their cultural identities, as called for by Ladson-Billings' criteria. Each of these components – the curriculum, the teacher competencies, and student co-creation – were essential in the development of the course described in this dissertation.

Research on Culturally-Relevant Pedagogy

Van Hamme (1996) claimed that "classroom approaches that are responsive to the children's cultures promote academic achievement by providing cultural relevance and a rationale for accepting school" (p. 21). What follows in this section is research from the literature that support this claim.

Ladson-Billings' (1990; 1992a; 1992b; 1994; 1995a; 1995b) research was an in-depth investigation of the practice of eight outstanding teachers of African-American students, as identified by the parents of the students with whom these teachers worked. The teachers were interviewed at the start of the study, and Ladson-Billings then observed their classrooms over two years. The teachers' classrooms were videotaped, and the teachers viewed and analyzed their own and each other's videos. "It was during this phase of the study that formulations about culturally relevant pedagogy that had emerged in the initial interviews were confirmed by teaching practice" (Ladson-Billings, 1995b, p. 472).

All of Ladson-Billings' teachers met the three principles she outlined as essential for culturally-relevant pedagogy, though they manifested them in a variety of ways with no consistent set of teaching strategies or approaches being espoused across the board.

Rather, what Ladson-Billings found was that the teachers' commonalities were in their conceptions about themselves, their students and knowledge, and in the way they structured social relationships in among the members of their classes. "The common feature they shared was a classroom practice grounded in what they believed about the educability of the students" (1995b, p. 484). The teachers believed in all their students' ability to succeed, viewed their teaching practice as a continuously evolving art form, had a high level of involvement with and connection to the community, and had a strong sense of personal agency with regard to their own abilities to support student success. They maintained equitable relationships with the students, sharing power with them, and promoting each student as a source of knowledge. They also encouraged a community of learners where each student worked collaboratively with the others to ensure the success of all. The teachers held constructivist, sociocultural notions of knowledge – knowledge is constructed and shared, students could be experts as well as the teacher, and new knowledge could be built through teachers' scaffolding. Knowledge was viewed through a critical lens, and assessment accounted for varying ways of demonstrating expertise.

Trout's (2005) research question was, "What are the effects of culturally relevant math history lessons on students' attitudes towards the discipline"? (p. 117). Trout's study investigated the influence of culturally-relevant math history lessons on one class of predominantly African American high school students' attitudes toward math. Data collection included both quantitative measures (Likert scale pre- and post-surveys) and qualitative measures (student interviews). The quantitative data showed no significant difference between students' pre- and post-lesson attitudes toward math. However, the researcher found in the interview data that in the post discussions, students exhibited more ownership of their successes, were able to cite examples of people using math to solve real-world problems, and took a more critical stance toward how dominant culture interprets the history and knowledge of people of color; that is, there was more evidence of meaning making and personal relevance that was not visible through quantitative measures.

Patchen and Cox-Petersen (2008), whose research involved case studies of two White elementary teachers based on classroom observations, interviews and field notes, found that although the teachers espoused constructivist pedagogies, and their teaching included some elements of culturally responsive teaching, actual instances of promoting student agency in the classroom were lacking. Despite substantial student participation, the teachers did not build upon student thinking despite soliciting it. Notably, "one of the biggest gaps [the researchers] found was in the neglect to discuss or recognize power relationships either inside or outside the classroom" (p. 1011), an essential component of cultural relevance as acknowledged by Villegas (1988) and Ladson-Billings (1995a).

Nevertheless, the teachers were trying and succeeding in some cases, and the researchers stressed the importance of the fact that the teachers wished to promote cultural relevance and that they were trying. This quote from one of the teachers illuminates how this approach looked in action: "I just read [the students'] body language, their desires, their questions, and we just move to where they are going. I look at [instruction] like a river. There's an end goal. I don't know how we're going to get to that end goal…we might do a lot of off shoots…I really pick up on where [students] lead me and how we go. If I have a plan that goes straight, they may take me sideways or somewhere else. I know my end goal. I start at the beginning and we'll get to the end goal, but I don't know the middle" (Patchen & Cox-Petersen, 2008, p. 1003). The authors identified this teacher's willingness to defer to the students for direction the class will take, to share authority, and to create space for student interest, as key elements to developing a culturally responsive classroom.

Kamehameha Schools in Hawaii did a large mixed methods study called Hawaiian Cultural Influences in Education, incorporating student surveys; interviews with students, parents and teachers; reading and math achievement data; and information on teacher practice related to culturally relevance (Assembly of First Nations, 2012). Culturally-relevant teaching practices were statistically significantly linked to higher student self-efficacy and sense of identity, higher math and reading scores, higher graduation rates, and students who were more likely to have an expectation of graduating from college.

While what exactly it is that teachers do to promote cultural relevance may be difficult to pin down, look different for each teacher, and only incompletely match the theoretical ideal, in places like the Kamehameha Schools, such practices do result in concrete, positive outcomes for students. As Ladson-Billings' and Patchen and Cox-Peterson's research both suggest, the principles and beliefs underlying classroom practice outshine the practice itself in terms of manifesting the goals of cultural relevance. However, the institutional buy-in and support from the Kamehameha Schools cannot be underestimated as an influence on positive student outcomes. The literature underscores the importance of both teacher and institutional factors.

Developing Culturally Relevant Pedagogy for American Indian Students

This section summarizes the theoretical literature with recommendations for instructors about creating culturally-relevant curricula. One of Nelson-Barber and Estrin's (1995b) "Assumptions and Principles for Improving Pedagogy" is that mainstream teachers should learn from non-mainstream teachers about how to teach students from non-mainstream cultures, seeking "examples of culturally-responsive practice and insights into interpreting performances" of these students (p. 42). Effective methods for American Indian students mirror home and community teaching styles, where teaching is often non-directive and incidental (Grant & Gillespie, 1993). "Children learn skills through experience with adults, not by having adults tell them what to do according to a recipe or by rote" (Reyhner, 2002, p. 15). Classroom teachers can improve their practice by moving from lecture and cookbook-style lab work in favor of engaging students in more hands-on activities that "correspond to 'learning from the land'" (p. 7).

A "Story Teller" format (Campbell, 1991, p. 108) can be used to help students contextualize and make meaning of new information, analogous to the way that children learn important information about their societies, and the way that this information is passed on from generation to generation. Traditionally, stories passed on what might be called "content knowledge", such as how to plant corn or how to skin a deer, but were also a means of communicating fundamental values and expectations held by the community (Van Hamme, 1996). Talking circles, as described by Running Wolf &

Rickard (2003), are another authentic means of passing knowledge and values through speaking and listening. This method was, and in some places continues to be, a traditional form of education for childhood through adulthood. “This method of education instilled respect for another’s viewpoint and encouraged members to be open to other viewpoints by listening with their heart while another individual speaks” (p. 39).

Holistic methods tap into many American Indian thinkers’ ability to experience the totality of a system. “The ability of many American Indians to see unity and wholeness without building from detail is not well served by the frequent classroom practice of introducing material in an analytic, sequential manner with the global view presented only at the end of the sequence of details” (Van Hamme, 1996, p. 6). Therefore, lessons should be structured around the whole, for instance by presenting the material in a narrative form (Reyhner, 2002). As well, for many Native people a sense of place is deeply imbedded in their consciousness. “Geography is not only a matter of location, distance, and elevation, but is additionally permeated with meaning and cultural significance. Indeed the worldview and cosmology of many indigenous cultures is indistinguishable and inseparable from the physical geography” (Riggs, 2005, p. 8). Tying lessons to the local (or in the case of displaced tribes, the homeland) environment will help increase their relevance to Native students (Barnhardt, 2000).

Hermes (2000), among others (Campbell, 1991; Kawagley, Norris-Tull & Norris-Tull, 1995), recommended integrating the community into schooling in order to learn from community members and to broaden the conceptualization of what the culture is. Campbell (1991) wrote that education is most authentic and meaningful when it involves the participation of community members of all ages engaged in genuine tasks. "Children learn by listening, observing and experiencing. Their teachers are all members of the community. The belief is that no one person knows everything, but each has an understanding of some part of the whole" (p. 102). Kawagley described this community-rich learning environment as it relates to Yupiaq education: "A classroom reflecting Yupiaq culture looks and feels much like the village outside the classroom door. Groups of individuals of all ages, from young children to the elders of the community, are engaged in hands-on activities, working together to complete meaningful tasks or to solve concrete, multifaceted problems relevant to their daily lives…Teachers and community members work together to assist students in strengthening their identification with their own culture while simultaneously embracing [school knowledge, e.g. Western science] as a second force that can help them maintain self-reliance and self-sufficiency" (Kawagley, Norris-Tull & Norris-Tull, 1995, p. 7-8).

A caveat for enthusiastic non-Native teachers is that they should recognize that they will probably not be welcome to teach American Indian language and culture in schools (Reyhner & Jacobs, 2002). A Pueblo leader is quoted in Belgarde, Mitchell and Arquero's (2002) article: "Do not teach our children our culture. Use our culture to teach them" (page 42). Hermes (2000) proposed that academic subjects be named by intellectual tradition, e.g. rather than teaching "science" (which assumes that such science is universal and acultural), be forthright in stating that you are teaching "Western science" (or Mesoamerican science, or Chinese science, etc.). A caveat, however, is to be aware of the risk of essentializing cultural sciences (Agrawal, 1995; Barca & Arenas, 2010); in fact, like virtually all cultural endeavors, there are many similarities and mutual influences across different sciences.

Hermes (2000) wrote, “The answer to the question ‘who will we be as Anishinabe in this classroom?’ is not a closed question.” That is, if students are not told “this is an Ojibwe class” they don’t draw lines around the Ojibwe and non-Ojibwe parts of their identities; “they are supported to bring all of their experiences into the room” (p. 395). As she concluded, “Categories that separate academics from culture tend to narrow the identity of ‘Indian’ and could be misleading for a Native American student who likes to draw both eagle feathers and Nintendo images” (p. 395). Students’ cultural identities are not delineated from other parts of their identities; rather, all of what makes them who they are, all of the choices they make and the things that they do, are expressions of their cultural identity in their personal reality. “Teaching *about* a culture is different than making students feel their culture is alive in their classrooms” (p. 396; emphasis added). While the teacher may not be presenting something from the material culture, it does not mean that other elements of the culture, such as relationships, values, spiritual beliefs, etc. should not still be present. This is relevant in school environments where “academic” content and “cultural” content are seen as two distinct categories.

Ideally, “effective transmission of knowledge to the American Indian child can be seen in the light of how traditional content can reshape the coding of academic information” (Agbo, 2001, page 44). However, as Nelson-Barber and Estrin (1995b) pointed out, “Students cannot be expected to make automatic connections among the different realms of theory and practice, so teachers need to help students see these connections" (p. 42). Similarly, Barnhardt (2000) advised, "Whatever piece of the curriculum you are responsible for, imbed it first in the world with which the students are familiar and work outward from there" (p. 173). For that to take place, the teacher needs to be able to see such connections too, and for a non-Native instructor or anyone coming from outside the students' culture, this takes time and experience. In fact, Trujillo, Figuiera, Viri & Manuelito (2003) did a qualitative study that found that Native preservice teachers valued the need to include language and culture in the curriculum, but did not feel they had been prepared to do so. So whether Native or non-Native, the challenge of incorporating culture is great.

It has been proposed that teachers who are first starting out in Native communities can begin using culturally-relevant practices by relying first on constructivist methods (Hankes, 1996), as there is some correspondence between culturally-appropriate teaching for Native students and the principles of constructivism as applied to all learners. Both are student-centered, build on what students already know, make new knowledge relevant by connecting to students' experiences, and view learning as an active process on the part of the learner. "Setting up a structure where students can learn the skill of a discipline, and yet draw on their own experiences and background to fill in the specific content, invites students to bring their home culture into the classroom" (Hermes, 2000, p. 395). Ethnomathematics, for example, transforms traditional everyday math into standards-aligned curriculum by first studying how math is used in the community. It taps into prior knowledge, acknowledges the value of the students' culture, and builds and helps develop higher order skills instead of being trivial (Apthorp, D'Amato & Richardson, 2002).

In order to engage with the rest of the world, Native students need to be proficient in the skills needed for life and economic competition in the mainstream (Agbo, 2001), so a balance must be struck between Native and European-American educational approaches in order to prepare students for success in both worlds. Finding that balance is difficult, and will be unique for each school (Gallagher, 2000), thus the importance of communities and schools working collaboratively.

Research on Culturally-Relevant Pedagogy for Native Students

Demmert and Towner (2003) conducted a literature review on the research about the influences of culturally-relevant education on Native American students' academic success, and found only five experimental or quasi-experimental designs that met the criteria of being both culturally-relevant and methodologically sound (Tharp, 1982; Omizo, Omizo & Kitaoka, 1998; Omizo & Omizo, 1989; Lipka & Adams, 2002; Kratochwill, McDonald, Young Bear-Tibbitts & Levin, 2001). Demmert and Towner described Tharp's (1982) research on the Kamehameha Early Education Program (KEEP) in Hawaii as "among the best-described educational programs in history…It is also probably the strongest evidence available for the efficacy of the culturally based education hypthosis" (p. 16). Although KEEP has been very successful, Demmert and Towner cited the researcher's cautions that the culturally-based elements of the program alone are not sufficient to replicate the success of the overall program, which has multiple intertwined components.

While the Omizo and Omizo (1989) and Omizo, Omizo and Kitaoka (1998) research saw successes from their culturally-based initiatives to improve the self-esteem of Native Hawaiian students, Demmert and Towner found a lack of a solid argument that such increases in self-esteem would relate to improvements in academic success. Lipka and Adams' (2002) work focused on the Math in a Cultural Context project at the University of Alaska Fairbanks, which has produced a series of culturally-appropriate modules in science and math for Alaska Native students; this article cited significant learning gains among students who used a module on perimeter and area as compared to students using a control curriculum. However, Demmert and Towner urged caution in the interpretation of these results due to potential issues of treatment validity across the teachers as well as potential issues of reliability with the statistics used (i.e. percentage scores in lieu of raw scores; gain scores versus matched two-way analysis).

Finally, the Kratochwill et al. (2001) study adapted a national early-intervention program utilizing parental involvement for Menominee students and evaluated its effectiveness, finding that the program was adaptable for this population. However, although involving the community in schooling, the program did not specifically address culturally-relevant curriculum or student achievement. "As it stands," Demmert and Towner concluded, "there are virtually no quantitative data that give us clear or definitive answers about the direct impacts of culturally based education on children's school achievement" (p. 33). The exception, according to Demmert and Towner, is the KEEP study.

Why might quantitative designs be few? Demmert and Towner (2003) identified issues of time (seeing an effect from culturally-based interventions could take many years), ethics (placing students into controlled groups where some receive an intervention and others don't is unfair to all students), and measurement (valid, culturally-appropriate instruments that can detect the effects of an intervention are difficult to create). Additional factors include the fact that Native populations, and classrooms of Native students in particular, tend to be small. Even meta-analyses are difficult because each community, and by extension the educational initiatives applicable to each, is disctinctive, making it inappropriate to attempt to analyze data across communities. In addition, when there are sufficient students to allow for experimental design, and some way to address the ethical issues of using it, validity issues arise when educators have a strong belief in culturally-relevant practices, swaying the results. Above all, experimental methodologies are often not aligned with the needs and values of the communities, where Indigenous groups tend to have less desire to isolate variables than to develop holistic understandings of the interactions of variable. Lipka et al. (2005) pointed out the following in reference to the mixed methods used in their study, for instance: "the quantitative methods do not provide insights about how curriculum is enacted, nor do they illuminate student–teacher interactions that may contribute to students' improved performance...It is the detailed ethnographic descriptions and analyses that show the interaction between the curriculum, the community, and the local culture, and between teachers and students, that help us understand how to improve student learning" (p. 368).

The quasi-experimental research described in Lipka and Adams' (2004) article investigated whether a culturally-relevant module on perimeter and area designed to reflect the realities of Yup'ik communities would have a significant effect on the math performance of sixth-grade students, as compared to a control group that used a standard textbook. The researchers found that the culturally-relevant curriculum did result in significantly higher achievement for the treatment groups compared to the control group, and the effect was more pronounced for urban versus rural students. The intervention also mitigated the performance gap between rural and urban students; the gap between the rural treatment group and the urban control group narrowed, while the gap between the two control groups widened. However, the urban treatment group gained more than any other, and the gap between the rural and urban treatment groups widened even more. Because the researchers did not have oversight in the control and treatment classrooms, it is impossible to know if the teachers (who were randomly assigned to teach the treatment and control curricula) were faithful to their assignments. Nevertheless, the researchers concluded that the culturally-relevant curriculum "can improve performance differences in mathematics for rural Alaska Native (Yup'ik Eskimo) students" (p. 28).

Two case studies of teachers working with the Math in a Cultural Context curriculum (Lipka et al., 2005) focused on the factors that contributed to increased student success. The teachers were chosen from a larger quantitative study of student mathematical gains in the classrooms of teachers using a culturally-based curriculum, as compared to students whose teachers used traditional math curricula. The two teachers were identified for being effective, as measured by students' posttest gains, and because they were from contrasting backgrounds – one an insider (who was raised in the Yu'pik culture) and the other an outsider (who was raised in the mainstream culture). Both teachers were found to have created student-centered learning environments utilizing guided inquiry, group work, and dialogue among the students and teacher. The learning goals were open-ended and allowed for student discovery and co-construction of knowledge.

Kanu's largely qualitative study (2006) also identified critical elements of instruction that, in this case, contributed to Native Canadian high school students' academic achievement, attendance, and participation: teachers' self-efficacy, teachers' capacity (essentially teacher quality with regard to interactional style, commitment, expectations for students, and content knowledge), student learning outcomes that included Native perspectives, culturally appropriate teaching and assessment, community participation, and a nurturing classroom environment.

Challenges and Criticisms of Culturally-Relevant Pedagogy

Stephens (2001) outlined the strengths (p. 7) and challenges (p. 8) of a culturally-relevant curriculum, particularly in the sciences:

Strengths:

- It recognizes and validates what children currently know and builds upon that knowledge toward more disciplined and sophisticated understanding from both indigenous and Western perspectives.
- It taps the often unrecognized expertise of local people and links their contemporary observations to a vast historical database gained from living on the land.
- It provides for rich inquiry into different knowledge systems and fosters collaboration, mutual understanding and respect.

- It creates a strong connection between what student's [sic] experience in school and their lives out of school.
- It can address content standards from multiple disciplines.

Challenges:

- Cultural knowledge may not be readily available to or understood by teachers.
- Cultural experts may be unfamiliar, uncomfortable or hesitant to work within the school setting.
- Standard science texts may be of little assistance in generating locally relevant activities.
- Administrative or community support for design and implementation may be lacking.
- It takes time and commitment.

Phuntsog (1998) identified another challenge for cultural relevance: resistance by teachers and schools. There are several reasons for this resistance. For one, schools may hide behind "color-blind" one-size-fits-all approaches, failing to acknowledge that schooling is not culturally neutral, and that "default" positions in schools almost always favor students from the dominant culture. Some educators fear that utilizing culturally sensitive approaches is akin to lowering the standards for some students, or giving some students special treatment. These educators are working under the assumption that uniformity equates to equity.

From the other side of the argument, there are educators who frown on the use of culturally relevant curricula because they see it being used inappropriately. Insufficient teacher training in multicultural education leads some teachers to seek methods shortcuts that undermine the purpose of culturally relevant education. They may inappropriately use curricula and methods designed to be used with one group of students with other groups. They may over-simplify culturally relevant approaches, reducing broad descriptions of, for example, “the American Indian learner” and conclude that Native students *cannot* learn abstract concepts or through reading (Phuntsog, 1998).

Hermes (2000) described a similar but distinct problem in culturally-based curricula, where classes and curricula are divided into two mutually exclusive categories of “academic” and “cultural”. Hermes identified three obstacles to student success from the superficial split between “cultural” and “academic” curricula. For one, it forces students to choose between a cultural and an academic identity, making academic success dependent upon assimilation – as troubling a dilemma, in fact, as that described when no cultural inclusion is present at all. In addition, the dichotomy positions the culture as anti-intellectual, promoting institutional racism. Lastly, the split causes teachers to have to “insert” culture into pre-existing, dominant-culture curricula, rather than using the culture as a foundation for developing curricula. As Hermes related, “In the way many schools are organized it seems as if there is one curriculum superimposed upon another” (p. 388); this, by extension, fixes the culture into a static entity rather than allowing it to be lived. This problem results when communities unquestioningly accept the structures of dominant schooling, and adopt an “essentialist” view of culture, which views culture as static and strictly delineated.

Frank Dukepoo (in James, 2001, pp. 3-42), founder of the National Native American Honor Society and founding member of the Society for Advancement of Chicanos and Native Americans in Science (SACNAS) and the American Indian Science and Engineer Society (AISES), freely admitted that he did not include culture in his classes on genetics, writing "I do not integrate culture into the classroom because information and techniques should be culture free, even if their application often is not" (p. 39). His assumption that knowledge and the teaching and learning of that knowledge can be separated from culture is untenable, as all things are imbedded in culture; ignoring this fact implicitly tells students that they must ignore their cultural perspectives in order to be successful in science. Dukepoo's educational philosophy may have been based on what Clifton Poodry (in James, 2001, pp. 29-35) referred to as "an N of one," where if going through the educational system ignoring the influence of culture on the construction of knowledge worked for Frank Dukepoo, then it must be a successful model.

As evidenced by these examples, resistance to cultural relevance in the classroom comes from both in and outside Native communities, and there is certainly wisdom in these cautions. There are ways that culturally-relevant curricula can be both developed and used inappropriately, and there is a need to educate teachers and teacher educators about why culturally-relevant curricula are necessary and how to promote cultural relevance without oppressing the culture. As well, enthusiasm for cultural relevance must be tempered by consideration of insufficient access to information and cultural experts, and wariness of schools (that they may open the doors to criticism from the community), teachers (that they may lose control of the curriculum) and community members (that their traditions may fall victim to exploitation). Further, philosophical differences about what is best for students will color individuals' interpretation of cultural relevance.

Cultural relevance in science

Science as Cultural

Chang and Rosiek (2003) wrote about the "hegemonic thinking" in regard to Western science: "the widespread belief that scientific knowledge transcends culture and therefore science teachers do not need to think about the implications of cultural diversity for their curriculum" (p. 252). According to Smolicz and Nunan (1975), the mythology of school science is that only Western scientific knowledge is "true" knowledge, despite the existence of a multitude of flavors of culturally-based knowledge of the natural world. Krugly-Smolska reacted to the following quotation in her (1994) article, stating her position that "few in the scientific community would take exception" to this belief: "Primitive religions, folklore and old wives' tales are full of explanations of why things are as they are. Such explanations reflect the human need to know, but they are based on ignorance. And this ignorance, in effect, is a lack of satisfactory means of probing the mysteries of nature. The essence of the scientific method is its concern for evidence as opposed to hearsay" (Morris, 1983, p. 37). Krugly-Smolska continued, "What is disturbing about this quotation is the implicit assumption that the explanations from folklore and old wives' tales were not based on evidence" (p. 326). The irony of the position, as she describes, is that, given the fact that most "scientific" knowledge is constructed by only a few and the body of scientific knowledge is too large for any one person to discover on their own, this information is shared via the very same means as wives' tales and folklore – through telling, from parent to child, media to consumer, or teacher to student; in other words, most scientific knowledge from the Western tradition is, to the non-scientist, a collection of folklore.

Cajete (1999a) acknowledged that there are those that claim that indigenous "folk knowledge" is not science because science is an invention of Western society. He argues that this perception is one of many that have used the Western "norm" to trivialize Native knowledge and deny Native cultures credence. "Whether there exists an indigenous science in western terms is largely an incestuous argument of semantic definition…The fact is that Indigenous people *are*, they exist and do not need an external measure to validate their existence in the world" (p. 81-82; emphasis in original).

Some may refuse to bestow upon indigenous knowledge the moniker "science" because it doesn't look like Western science. Baker (1996) describes three popular views of what others have called Native science:

1. Science is inclusive of people from all cultures, but requires that they accept the "rules" of science (i.e. logical empiricism).
2. Indigenous science is distinct from Western science but can inform it – a multicultural perspective.
3. Indigenous science and Western science are not separate sciences, but involve different ways of looking at the world; that is, different worldviews – a sociocultural perspective.

Proponents of the first view are those who are unable to look at other culture's means of gathering information about the world as being scientific. Rather, they think of science as an invention of Western culture; as Baker describes, other cultures can participate in "Science", but only if they are willing to play by its rules. This is essentially an assimilationist perspective. According to Kawagley, Norris-Tull and Norris-Tull (1995), "The hegemony of Western science threatens to further disenfranchise indigenous cultures and perpetuates a colonialist attitude that cannot be defended in modern times" (p. 3).

Western science does have a privileged position by virtue of the fact that it belongs to those whose culture is dominant in today's society, but it is not culture free; its claims of objectivity and universality are interpretations given to it by those who designed it. As Kawagley, Norris-Tull and Norris-Tull (1995) argued, "That Western science has become the prototype for what counts as science today is not an indication that this is the only true science. Rather, it is the result of the dominance of Western culture over other cultures, to the point that other ways of thinking and doing science have been largely discredited by the Western scientific community in general and by modern educators in Western cultures" (p. 3).

Western science is still imbued with the value systems of those who practice it. Zacharias and Calabrese Barton (2003) suggested that the norms of science are socially-constructed; as Fusco (2001) wrote, the "enactment of science must be understood in relation to the sociopolitical and cultural context in which science is occurring" (p. 869-870). James (2001a) also made a strong case for the subjective in science, describing how the values of the society drive what research is funded and how the results of the research are used. Similar statements have been made by Driver, Asoko, Leach, Mortimer and Scott (1994), who wrote that “The objects of science are not the phenomena of nature but constructs that are advanced by the scientific community to interpret nature” (p. 5), and by Nelson-Barber and Estrin (1995b), stating that “Scientific knowledge is both symbolic and socially constructed” (p. 16), an unavoidable condition of the human experience: “Humans are limited by the perceptual, processing, and cognitive capacity of their brains; it is not possible to have objective or perfect knowledge about the universe and its ‘laws’” (p. 18).

Cobern (1991, p. 19) wrote that worldviews, or “the culturally-dependent, implicit, fundamental organization of the mind…composed of presuppositions or assumptions which predispose one to feel, think, and act in predictable patterns” of different ethnic groups influence their cultures’ perspective on the natural world; hence, their sciences are different. Proponents of the second of Baker’s views only accept Western science as the principal form of science, but do at least acknowledge the contribution of other cultures’ knowledge.

Proponents of the third view, however, are those who recognize other cultures’ systems of knowing as science. To understand that Western science is but one of many sciences, one must first acknowledge that all science is cultural. “Observations are always made, first, within the historical and cultural context which has given someone the reason for making the observation at all and, second, within the context of the person’s own belief system and his own organism which in turn affects the results of his observation”

(Hayward, 1984, pg. 71). These cultural contexts impact the kind of science that is done and the meaning that is derived from it. Thus, science is situated within:

- The culture's assumptions about reality, which underlie all inquiry;
- The culture's values, which determine what is valid and what is not;
- The culture's priorities, which determine what knowledge should and should not be pursued;
- The culture's lenses, which color what is observed and how it is interpreted;
- The culture's ways of knowing, which dictate what is defined as knowledge and what is not; and,
- The culture's worldview, which defines what is knowable and what is not.

Each culture has its own form of science. All communities have had processes through which they gathered and organized knowledge about the world around them (Cajete, 1999a). "In our Native languages, Native science or traditional knowledge refers to scientific skills that Native people value and have used since the beginning of time to discover the dependable, repetitive, and tested way things work in the world. When speaking about Native science or traditional knowledge, one is really talking about the entire body of indigenous knowledge" (Lambert, 2003). Baker (1996) suggests that "the notion of indigenous science differs from 'western' science in its method and rigour, but not in its essential nature. Like 'western' science, indigenous science consists of a set of explanations which seek to make sense of the natural world and which are consistent with a particular worldview" (p. 19).

Murfin (1994) valued this diversity: “Because every culture’s way of viewing the world is different it seems probable that every culture may have developed unique strategies for doing science. Some of these may just possibly fill in the gaps in others. If the scientific knowledge of all cultures could be pooled and regarded with equal respect, the world would undoubtedly be an immeasurably richer place” (p. 97).

Native Science

An early definition of Indigenous science comes from Hardesty (1977), who referred to ethnoscience as the study of cultures’ systems of knowledge used to classify object, events and activities in their local environment. Native science helps Indigenous people make sense of their world, and is “knowledge built up through generations of living in close contact with the land” (Snively & Corsiglia, 1998, p. 13). Cajete (2000) referred to it as “the collective heritage of human experience with the natural world; in its most essential form, it is a map of natural reality drawn from the experience of thousands of human generations…In profound ways Native science can be said to be ‘inclusive’ of modern science” (Cajete, 2000, p. 3).

After being asked to contribute to an ethnoscientific research project investigating how Tohono O’odham elders classified plants and animals in their desert homeland, Tohono O’odham scholar Ofelia Zepeda (2001) wrote, “It was my impression that the O’odem people would never lay things out in little boxes so neatly. I did not think they would label and compartmentalize things so specifically. But it turns out that there are some people in the tribe who do exactly that…To my amazement, a group of elderly traditional hunters were able to label and organize animals very clearly in the O’odem language. They had definitions of different species and described the relationships among the species very precisely” (p. 59). Such systems of knowledge, though they may not be written down, have been built over generations to facilitate the work that hunters do and, in turn, to ensure the survival of the people.

“People who do not use writing rely more on their sensory perceptions and have developed certain mental capacities of observation that many non-Indians have lost” (Pewewardy, 2001, p. 20). Simonelli (1994) refers to Indigenous science as a “full-spectrum science” that “draws freely on all four of the gifts that have been given to us as human beings: the spiritual, emotional, mental, and physical. By contrast, Western science dwells mostly on the physical and mental, often rejecting the spiritual and feeling or emotional qualities of life with great arrogance and finality” (p. 37). Dyck (2001) wrote, “In Aboriginal science, we would accept intuitive knowledge and look for a holistic world-view that integrates it with logically and rationally derived knowledge.” She cited the role of creativity and intuition in many of science’s great discoveries, such as Kekule’s understanding of the structure of the benzene molecule through an image in a dream. Indigenous science is both observational and intuitive, and creates explanations of phenomena using both creative and logical capacities. Although scientists may describe their professional practice in different terms with a different approach, this picture of scientific inquiry beautifully describes the practice of science as a whole.

The knowledge and understandings constructed by Native peoples are typically communicated via stories. Snively and Corsiglia (1998) described how stories serve this purpose: “Large numbers of very intelligent indigenous peoples observe, interpret and orally report nature exhaustively. Rather than writing about their findings, they tend to use highly metaphoric stories to compress and organize important information so that it can be readily stored and received" (p. 30). Zepeda's (2001) description of how the O'odham hunters' scientific knowledge systems incorporated knowledge from their oral tradition supports this idea. "Oral tradition has patterns, schemas, and mnemonic devices that help you remember individual things and connect them to each other so that you can use each at the right time as well as present them effectively to others. That is why Native people do a prayer or a song the same way each time. Oral tradition is the way that the older generation learned things, and it is the way that they pass their knowledge on" (p. 59).

Oscar Kawagley (2001, p. 53) wrote,

> We as a Yup'ik people have our own science and have crafted our own mathematics. As in Western science, there had to be long and patient observations to build knowledge and theories based on distilled experience with events. That knowledge and those theories are handed down to us in our mythology, our stories, and our proverbs. Our math, our science, and the technologies we developed from them grew out of our world-view, developed from our own mind-set…We study each small piece of the world in which we live. Once we learn about it, though, we look for ways in which it influences people, influences other natural things, and influences the spiritual aspect of the universe. The holistic and spiritual components of our science are big differences from mainstream approaches…There is no such thing as objectivity in our world-view; we cannot and would not separate self from the thing that we are studying. The result is that each piece

> of knowledge is integrated with our complete cultural template, and generating that knowledge is done to help make our cultural template complete.

Kawageley's perspective of Yup'ik science and math reflected similarities from not only other indigenous sciences, but from Western science as well. All human endeavors are grounded within "our world-view, developed from our own mind-set." Like indigenous sciences, Western science cannot obliterate the person from the science (though it may claim otherwise). The lesson to be learned for science education is that teaching facts and skills in isolation is meaningless; knowledge about the world should be integrated into what students already know and feel and believe about the world. Failing to discover what students' cultural template is leaves instructors floundering to make any impression on them, and students struggling to understand why this information is meaningful.

The Crisis of Science Education for Native Students

Pewewardy alleged that "for science and technology to benefit Indian people, or for Indian perspectives to benefit science and technology, we have to understand our frames of mind and create a science and technology that fits with them" (Pewewardy, 2001, p. 20). Historically, this fit has been lacking from the science curricula available to Native students. Nelson-Barber and Estrin (1995a) highlighted the effects of this absence, writing that "critical opportunities to build on or draw from Indian students' existing knowledge are missed. At the same time, Indian students may feel both confused by classroom approaches to mathematics and science that are not grounded in experience, and denigrated by a system that appears to assume they know nothing about these realms" (p. 174).

Not surprisingly, science education for Native students has a reputation for being didactic, and traditional didactic teaching methods have communicated an objectivist view of the natural world that marginalizes others' worldviews (Wachtel, 1995). "Science has been taught through lecture, graded competitively, and involved remembering an enormous amount of unrelated abstract information with no clear use in real life" (Kawagley, Norris-Tull & Norris-Tull, 1995, p. 7). The decontextualization of information and the lack of sensitivity to students' cultural norms have prohibited students' ability to make meaningful connections to the material and to the field of science as a whole. Science may also be incongruent with students' cultural values (Lee, 2003); while Western science values objective, rational reasoning, a student's culture may value emotional input, social collaboration, and consensus building.

The field of science itself has a legacy of marginalizing Native communities, such as when anthropologists dig up human remains, and when mining engineers leave behind nuclear waste (Levy, 1992). As a result, even being associated with science can lead to students' marginalization from their peers. As one student described, "Other kids thought I was conforming to the 'white society' by pursuing my interest in science. The other pressure was that science was bad, that all scientists were Frankensteins, and that logical thought was unethical. There were several times where I was told that I was 'just like so-and-so,' where so-and-so was some sort of bad person such as Hitler. My uncle once told me that I could never be successful in science and culturally Native American" (Curran, 1995).

The lack of scientifically skilled individuals in Native communities has crippled these communities, leaving them unable to identify and address serious issues such as health problems, environmental problems, and the education of their youth (James, 2001b). "[S]uccessful governance certainly does require access to people with the technical knowledge and skills needed to protect communities and carry out community projects and plans. To maintain Indian control and keep resources circulating in Indian communities, as many of those skilled people as possible should be Indian" (p. 5-6). Dyck (2001) echoed this concern, referring to a need for Native scientists both for the sake of improving the well-being of Native communities by addressing community-level scientific problems, and to "change the way science is done" (p. 28). As Dyck wrote, "Aboriginal science can lead the way" in finding ways to "heal the hurt we have done to Mother Earth and to ourselves".

The goals of solving problems, living sustainably on the Earth, fostering the wellness of communities, and seeking a deeper understanding of the world and Universe around us can all be met by diversifying the perspectives of the field that strives to achieve them. As Cornel Pewewardy wrote (2001), if we want science to work for Native people, and Native people to change the face of science, the two cannot be at odds with each other. There must be a window of opportunity for Native students of science, a congruency, an overlap between Native and scientific ways of thinking. Pewewardy's words call for culturally-appropriate science teaching.

Characteristics of Culturally-Relevant Science Curricula

Gilbert John (2001) reported that he tells students that becoming a scientist “does not require abandoning tradition; instead, they will be more successful if they can find ways to fit science together with tradition. I know it can be done because I have done it, and I try to convince Indian students that it is also possible for them” (p. 66). It is important to note that such role models exist, that a person can be a scientific researcher in the world of academia yet still maintain an identity that is tied to their home culture. The question for educators is how to support the unification of these dual realities by blending them in the classroom, a purpose that the development of culturally-relevant science curricula is designed to serve.

Stephens (2001) defined culturally-relevant science curriculum as integrating both Native and Western epistemologies to promote students’ learning and psychological well-being. The pedagogy behind a culturally-relevant science curriculum “assumes that there are multiple ways of viewing, structuring, and transmitting knowledge about the world – each with its own insights and limitations…and regards them as complementary to one another in mutually beneficial ways” (p. 7). Stephens advocated for pedagogies and teaching practices that reflect the principles of cultural relevance, but within the context of science. Kawagley, Norris-Tull and Norris-Tull (1995) emphasized interdisciplinarity in culturally-relevant science for, in their locality, Native Alaskan students. “What emerges from incorporating Native Alaskan world view, knowledge, and culture into Alaskan schools is a curriculum which integrates the natural sciences with social sciences, language arts, humanities, and mathematics in a way which the learner can recognize as having legitimate meaning in daily life" (p. 7).

Cajete (1999a) developed a model of science curriculum development, promoting a culturally-based science curriculum with the following characteristics (p. 126). This model demonstrates for students the relationships between the content and their cultural identities:

- Applies the principle that we come to learn and we *can* learn science from many different pathways.
- Teaches for connecting to a "sense of place", a homeland.
- Facilitates learning to appreciate land by living on it.
- Creates an extended family of learning by including community members, both young and old adults.
- Involves Elders and "special" community members wherever appropriate.
- Works from a cultural context to make meaningful connections of science to students' lives.
- Teaches through authentic learning experiences.
- Creates a foundation for cross-cultural understanding.
- Develops a flexible schedule for learning.
- Emphasizes sharing and giving voice and vital expression to one's thoughts.
- Facilitates personal experience and achievement.
- Develops a foundation for healthy responsible living.
- Gives students practice in applying their leadership skills.

- Introduces Western Science, cultural and environmental studies through immersion, observation, appreciation and exploration with all the senses.

Cajete's model utilizes an interdisciplinary approach that connects science to other disciplines such as art, history, philosophy and language arts. It also recognizes the social and constructivist natures of learning, in which students interact collectively to build new knowledge from their existing knowledge. The science curriculum is imbedded in the community; learning is connected to place, is both personal and collective, and is directed toward learning how to live healthfully within a place and a community. As well, indigenous and Western sciences are taught alongside each other, using one as a metaphor for the other and illuminating their similarities and differences. The curriculum's goals are both to strengthen the cultural identity of the students and encourage them to appreciate the scientific knowledge of their cultures, and to help them develop skills that will allow them to be successful in a technology-oriented economy. It relies on multisensory activities that mimic the way science was learned in traditional societies: through hearing, smelling, touching, manipulating, etc. It fosters a love for the natural world, particularly students' immediate environment, and stresses that science is a creative process, encouraging students' creativity in learning about and describing scientific knowledge. "Pedagogy that thus draws from indigenous knowledge, world view, and culture provides students with not only a locally relevant science education, but also in many ways provides them with the kind of learning environment and experiences recommended for students everywhere" (Kawagley, Norris-Tull & Norris-Tull, 1995, p. 8).

Later, Riggs (2005, p. 6) determined that culturally-responsive earth science curricula for Native students shared the following characteristics; these recommendations can be extended to other fields of science education as well.

- Major emphasis on place-based curricula, emphasizing experiential, outdoor learning in familiar environments within the traditional homelands of the indigenous groups.
- Inclusion of relevant indigenous scientific knowledge wherever possible and appropriate.
- Explicit involvement and cooperation of indigenous community members, elders, and educators in the design of the content, location, and delivery of curricula and programs.

Experiential education is but one aspect of appropriate science education curricula, but it is an important one. According to Swisher and Deyhle (1992), Native students seem to "learn in their natural settings experientially" (p. 86). Reyhner (2002) would agree: "Teachers need to get students out of lecture halls and textbooks and get them involved in 'real' experiences – especially hands-on activities. These kinds of activities correspond to 'learning from the land'" (p. 7). Science education, for all students but especially Native students, should be experiential, encouraging students to participate in and learn from their local environments, utilizing hands-on and project-based activities to increase students' ownership of the material. Grounding new concepts in students' experiences gives them a concrete understanding of what the concept is and why it is important. For instance, in Tucson it can be a relatively short walk from an area with a maintained landscape, e.g. the University of Arizona, to an area that is natural desert. The very same types of trees in each location are at staggeringly different heights, because the landscaped trees get regular water and the naturally growing trees get sporadic rain. Students can experience the difference and take note of it, and the importance of water for plant growth becomes obvious.

Comparing Native and Western Perspectives.

Snively (1986) wrote that science instruction can increase the scientific understanding of Native students without conflicting with their beliefs, but in order to do this, Snively and Corsiglia (1998) eschewed the subtly-assimilative approach of overwriting students' existing knowledge with Western science knowledge, writing that "the focus of instruction should not be on presenting information so that children of ethnic minorities can *accept* the scientifically accepted notion of the concept, but on helping students *understand* science concepts and to explore the differences and similarities between their own beliefs and western science concepts" (p. 37). Students should be guided to see how the two (or more) epistemologies are different but also how they are similar, stressing "areas where [indigenous knowledge] helps fill the gap where knowledge in [Western scientific knowledge] is lacking, and vice versa" (p. 41).

Cajete (1999b) wrote that what he calls a *bicultural approach to science instruction* "provides a way to bridge differences in worldview concerning natural phenomena" (p. 136), incorporating a space for comparing different worldviews represented in science as well as a space where students can discuss and examine their values. "This process sets the stage for students to synthesize creatively and interpret these values in new and psychologically rewarding contexts” (p. 139-140). Cajete considered this to be essential for motivating Native learners. “A Native student’s constellation of values has ancient and well-developed roots in the tribal social psyche…Understanding and using this cultural constellation of values can provide the key to motivating Native Americans to learn science” (Cajete, 1999b, 137).

Cajete (199b) stated that comparing epistemologies of science in the classroom “can help all students become more open and less isolated within the confines of a single cultural viewpoint” (p. 151-152). Hermes (2000) wrote about an interaction with her students as she introduced means of acquiring scientific knowledge, parallel with the chapter in the class textbook about “the” scientific method. In the interaction, she and the students talked about ways of coming to know about nature in an Ojibwe epistemology, and compared this with the ways of knowing embodied by a Western scientific method. By doing this, she attempted to teach the academic, standards-based curricular content without using it to replace cultural knowledge, and to reinforce students’ identities at the same time. “[I]f it makes connections – makes what students read in a textbook come to life with meaning, connect what they have lived to what they are learning, and connects to past traditions which are quickly being forgotten or abandon[ed] – then it is an act of deconstructing and appropriation that is in line with the mission of culture-based curriculum” (p. 393).

Ethics and Values

Nelson-Barber and Estrin (1995a) promoted the inclusion of “ethical and historical dimensions that situate science knowledge in a context…Questions such as, ‘What knowledge is important to the survival of our society, our earth?’ ‘To what use will knowledge be put?’ ‘What might be the effects of using knowledge in this way?’ would arise from taking ethical and historical standpoints” (p. 176). Snively and Corsiglia (1998) encouraged, within a classroom context of mutual respect and valuing different viewpoints, the inclusion of critical thinking questions that investigate the potential consequences of scientific knowledge, how different kinds of scientists come to know, as well as the interplay of power structures with issues of ownership and dominance.

Cajete (1999a) also reminded educators that curriculum, specifically in science education, should include spirituality. He explained the importance of spiritual values that make knowledge meaningful to students: “In every culture, the inherent thought process of science attempts to relate derived symbols of phenomena to one another in such a way as to develop a pattern of thought concerning those events. [Native American students] have some skill in relating important culturally derived symbols of phenomena within the framework of what is meaningful to them” (Cajete, 1999b, p. 147).

This approach has limitless fodder from the world of science. Students can investigate how Einstein’s work led to the atomic bomb, and come to their own conclusions about whether the science was worth the repercussions. They can look at whether advances in medicine have changed the course of evolution, or whether it is ethical for humans to adapt other planets to make them suitable for our habitation. Authentic questions like these, with real implications for the human race, not only spur investigation into scientific concepts, they also involve students in deep consideration of the nature and character of science.

Research on Culturally-Relevant Science Curricula

Like Cajete's model, a Diné College curriculum model reviewed by Nelson-Barber and Estrin (1995a) was designed to mirror a Navajo philosophy, grounded in the four directions. Faculty members "align their efforts to help students develop a balanced and harmonious life with four branches of knowledge: humanities and fine arts (knowledge associated with the east); professional and vocational studies (knowledge associated with the south); social sciences (knowledge associated with the west); and the natural sciences (knowledge associated with the north)" (p. 182). The researchers described how a science course aligned with this philosophy would show how all things were interconnected, how they are tied to human values and social systems, and how humans influence the natural environment. All elements of the course would reflect the Navajo worldview. If this model is successful, what benefits would it have for Native students?

Science instruction that is culturally appropriate, draws on students' prior knowledge, and is instructionally congruent – mediating between academic disciplines "with students' language and culture to make the academic content accessible and meaningful for all students" (Lee, 2003, p. 474) – has resulted in academic gains and more positive attitudes toward science for minority students (Matthews & Smith, 1994; Ballenger, 1997; Rosebery, Warren & Conant, 1992; Warren, Ballenger, Ogonowski, Rosebery & Hudicourt-Barnes, 2001; Fradd, Lee, Sutman, & Saxton, 2002; Lee & Fradd, 1996, 1998, 2001; Westby, Dezela, Fradd & Lee, 1999). These results do not specifically apply to Native students, but while the results may not be generalizable to Native students, the positive impacts may.

"To be creative, one has to have a strong base of knowledge both within a particular area and in general. A strong grounding in values, cultural symbols, and ceremonies often provides the raw materials, motivation, and rhythms needed for major creative contributions or effective innovations…Cultures, including the culture of science, must be flexible enough to restructure themselves as the world, circumstances, and events change, while also retaining a core of stability" (James, 2001a, p. 49). In other words, creativity, the development of new and novel ideas, depends both upon the possession of a strong knowledge base and the flexibility to modify culture without fundamentally disrupting it. Hence, Native learners who are grounded in their own culture have a resource from which to draw when solving problems; they may find that the solution to a tricky scientific issue can be informed by the philosophies and approaches that they know well.

Discourse Studies

The following sections explore meaning making from a discourse studies perspective, in which developing third spaces into which students can draw hybrid perspectives drawing from their myriad funds of knowledge, provides the potential for making meaning within culturally diverse classrooms.

Deloria and Wildcat (2001) discussed how education can connect mainstream and traditional American Indian worldviews, providing an opportunity for both to share with one another. As Ladson-Billings (1995b) wrote, "meaning is made as a product of dialogue between and among individuals" (p. 473). By including and valuing students' funds of knowledge in the classroom, a "third space" can be developed, in which the overlapping and intertwining of students' knowledge resources, the instructor's knowledge resources, and the Discourse of the content may result in significant opportunities for students (and the instructor) to create novel and unique understandings of the topic area. This blending of diverse ideas originating in diverse contexts is referred to as hybridity (Bhabha, 1994). Thus, the fact that an instructor and students come from different cultural backgrounds can be a strength rather than a liability.

Border Crossing

The mismatch between students' culture and the culture of the classroom and content can create obstacles for students. Citing students' frequent inability to transfer math knowledge used in everyday environments to the classroom and vice versa, Nelson-Barber and Estrin (1995a) noted, "It is as though there are semi-permeable membranes among every day, classroom, and academic realms of mathematics" (p. 179). Aikenhead (1996) related that learning science (and as an extension, learning math) is an exercise in "cultural acquisition", requiring students to "cross cultural borders from their life-world subcultures (associated with, for example, family, peers, school and media) to the subcultures of science and school science" (p. 40). If the student's culture and the culture of science/school science are similar, border crossing is smooth and the student acquires the culture of science; if the cultures are dissimilar, instruction demands that the student abandon their culture to learn the culture of science, resulting in students being alienated from one culture or the other. "As I move from one [social] reality to another, I experience the transition as a kind of shock” (Pewewardy, 2001, p. 20). This is an issue that Cajete addresses in his works: the splitting of Indian people by the pull of their Native ways and the pull of the dominant culture’s ways. Being forced to live between two worlds, while not having the opportunity to live fully in either, creates existential problems for Native people. Turning one’s back on Native traditions results in situations common among Indian people today: high suicide rates, alcoholism, abuse, helplessness, desperation. “Tewa people call this state of schizophrenic-like existence pingeh heh (split thought or thinking, or doing things with only half of one’s mind). As an Indian educator, I believe that modern Indian education ultimately has to be about healing this split” (Cajete, 1999b, p. 17). Science curriculum and instruction must concern itself with assisting students in crossing borders, but not with forcing students to assimilate into the science subculture at the expense of other ways of knowing.

Lugones (1987) posited that an individual’s ease in being in a culture is dependent on their flexibility, playfulness, being fluent in the culture’s language and norms, having a sense of the appropriateness of the culture’s norms, being amongst people with whom the individual shares mutual love, and sharing a common history. Ogunniyi (1988) found that scientific and traditional (in this case, indigenous African) systems of thought were “not necessarily mutually exclusive of each other” (p. 6), that they did not always conflict, and that it was thus possible to hold both. Teaching people about scientific thought did not eliminate their previous conceptions, but rather their traditional worldview “could be enlarged to accommodate the scientific point of view” (p. 7).

Likewise, Phelan, Davidson and Cao (1991) found that with help and support, Indigenous students were better able to cross borders between their home and community cultures and academic and professional cultures, but without such assistance they were only able to cross borders smoothly where there was a high degree of alignment between the different cultures. Aikenhead & Jegede (1999) described the degree of success for which students have the potential in a science class (i.e. the degree to which they will learn and understand) as dependent on three variables: “(a) the degree of cultural difference that students perceive between their life-world and their science classroom, (b) how effectively students move between their life-world culture and the culture of science or school science, and (c) the assistance students receive in making those transitions easier” (p. 270).

Researchers Aikenhead and Jegede identified a phenomenon they called *collateral learning*, in which students learn conflicting content (e.g. their cultural creation story and the Big Bang theory) side by side and may or may not make any attempt to reconcile them (Jegede, 1995, 1997; Aikenhead & Jegede, 1999). The researchers modeled collateral learning along a spectrum, where variation along the spectrum is dependent upon the degree to which the conflicting schemas interact. When the schemas do not interact at all, with one invoked independently of the other depending on the context for which it is needed, it is *parallel collateral learning*. Another possibility is *simultaneous collateral learning*, where the context for two schemas can overlap, e.g. when an event in the students’ home world suddenly evokes a concept learned in the classroom, reinforcing the concept. In *dependent collateral learning*, one schema challenges the other and results in the student modifying one without changing it fundamentally. With *secured collateral learning*, the student must both acknowledge and resolve the conflict between the schemas. This may result in a justification for maintaining both that is satisfactory to the student, or the development of a new conception in which the two schemas reinforce each other. Sutherland (2005) found that Cree science students with more protective factors (e.g. intrinsic motivation, family support, peer support) were more likely to engage in collateral learning, leading to meaningful learning.

Aikenhead and Jegede (1999) discussed the similarities between collateral learning and Posner, Strike, Hewson and Gertzoy's (1982) conceptual change model, in turn based on the Piagetian constructs of accommodation and assimilation; Aikenhead and Jegede's model adds the recognition of *cultural* assimilation, or as Aikenhead and Jegede referred to it, the degree of imposition on students, to the conceptual change model.

Jegede and Aikenhead (1999) argued that the role of the instructor is to be a culture broker (Chisholm, 1994; Stairs, 1995) for students: a tour guide (for students who have relatively more difficulty crossing borders) or travel agent (for students who are relatively at ease crossing borders) as they navigate the subculture of science (Jegede & Aikenhead, 1999). They related several examples of what culture broking looks like in the classroom. In one classroom, a bridge was created between the Nepalese cultural and Western scientific understandings of phenomena through small-group discussions on questions that invoked both systems of thought (Bajracharya & Brouwer, 1997). In another, students divided their notebook pages into two columns, one for “my ideas” and one for “culture of science” ideas, putting their thinking into one of the two column or both – this allowed them to learn about scientific knowledge without necessarily having to believe it (Aikenhead, 1996). Snively (1995) provided guidelines for culture broking with Indigenous science students, such as including Native stories and heritage in the classroom as valid understandings, maintaining a critical perspective of the dominant culture, allowing students to compare and contrast cultures and subcultures, integrating affective elements (e.g. spirituality, morality, ethics), and empowering students to solve problems and examine their own thinking – all of which bear the markings of culturally relevant pedagogy.

Scientific Identity

Gutiérrez, Rymes and Larson (1995) wrote about how gaining membership to a community of practice, such as the community of scientists, is “a process of developing a particular identity and mode of behavior; through participation in a community’s sociocultural practices, members learn which discourse and forms of participation are valued and not valued by the community” (p. 448). Brickhouse, Lowery and Schultz (2000) argued that a requisite for learning science is that students develop identities aligned with scientific identities. Brown (2006) found that internalized oppression (i.e. negative beliefs about one’s own cultural group, adapted from the perceptions of the dominant group) interfered with students’ ability to see themselves as current or future scientists. Several members of his student population described reasons why members of their cultural group tended not to become scientists, because of what the students believed to be common to members of the cultural group: lack of ability to focus and to follow through. Brown also saw students successfully aligning their identities with science in his interviews with minority high school science students; a student quote demonstrates how science learning can influence a student's perspective (p. 116):

> And when I came in this class, it's like I just started looking at things [different], you can kinda like, once you started studying it you can kinda look around. You can kinda see stuff in life that you talked about in science but you never really paid any attention to it.

Brown's interpretation of comments such as these from his student population was that they "marked a noted transition in [the students'] attempts to incorporate scientific ways of being into their identity frameworks" (p. 116).

As Brickhouse, Lowery and Schultz (2000) stated, "We need to know how students are engaging in science and how this is related to who they think they are (what communities of practice they participate in)…and who they want to be (what communities of practice they aspire to)" (p. 443). Learning science, as described throughout this chapter, is not only about assimilating content – it is a sociocultural enterprise that expands one's identity to create space for identification as a science learner or potential scientist. As Calabrese Barton, Tan and Rivet (2008) wrote, "Learning science involves not only learning content but also learning how to participate in science-related communities" (p. 74).

Science Discourse

Huang (2006) wrote, "Students' willingness and ability to cope with instruction/scientific discourse is critical to a successful border crossing" (p. 411). Huang investigated the discourse that students used as they learned scientific concepts and whether they were able to integrate scientific discourse into their personal dialogues, finding that the discourses students engaged were derived from a plurality of voices from their social, classroom, and scientific communities. A closer alignment between students' discourse and the scientific discourse facilitated their border crossing. This suggests that instruction about scientific discourse itself is important, as is actively listening to the language students use to describe their thinking.

Instructional congruence, as defined by Lee and Fradd (1998), is "the process of mediating the nature of academic content with students' language and cultural experiences to make such content (e.g., science) accessible, meaningful, and relevant" (p. 12). Instruction in the differences between scientific Discourse and everyday Discourses can facilitate students' success in learning science, particularly for students from minority cultures. This means, for instance, discussing with students how science uses words differently from their common usage (Duran, Dugan, & Weffer, 1998; Lee, 2003; Sutherland & Dennick, 2002).

Mortimer and Scott (2003) spoke of learning science as a transition in the language used to formulate one's understanding of a concept. "[L]earning in the sciences can be a difficult and challenging process for students, especially when there is a big gap between *everyday* and *scientific* ways of talking and thinking about particular phenomena" (p. 74). Mortimer and Scott drew on Vygotsky's (1934) work to describe learning as a process by which the learner internalizes into the individual plane the dialogue taking place on the social plane (e.g. amongst students and teacher). This involves what they called an "*individual meaning making* step" (Mortimer & Scott, 2003, p. 10, emphasis in original). "[M]eaning making is a dialogic process, which always entails bringing together, and working on, ideas" p. 11). Mortimer and Scott (2003) consider talk, whether by the teacher, the student, or both, to be the most essential part of the science classroom. "As we see it, school science offers an account, a kind of story, of familiar natural phenomena expressed in terms of the ideas and conventions of the school science social language" (Mortimer & Scott, 2003, p. 18). These researchers pointed out that many of the concepts in science are abstract and constructed in relation to other ideas; "Anyone who has ever heard a group of physics teachers debating 'what we mean by energy' will appreciate that scientific concepts do not carry unique meanings" (p. 11). The task for teachers is to draw out students' existing understandings and "develop convincing lines of argument to interact and engage dialogically with those existing understandings" (Mortimer & Scott, 2003, p. 19).

Arguments for an Authoritative Approach to Teaching Scientific Discourse

Although there is an agreement in the literature that students need to be exposed to scientific discourse in order to join the scientific community, there are two perspectives on how, and why, to do so. The authoritative approach is summed up by this quotation from Mortimer and Scott (2003, p. 106): "Students will not stumble upon, or discover, the key concepts of the social language of science for themselves" (Mortimer & Scott, 2003, p. 106). Like the researchers mentioned above, Fang (2005) argued that students need to become fluent in scientific discourse in order to be scientifically literate. Pointing to specialized characteristics of scientific discourse including lexical density, abstraction, technicality, and authoritativeness, Fang advocated for attention being paid to teaching students about science's linguistic conventions, but was opposed to including critical perspectives of the scientific discourse community, stating that scientific language "cannot simply be dismissed as technocratic, hegemonic, patriarchal, or oppressive" (p. 343).

Scott, Mortimer and Aguiar (2006) wrote, "we see a *tension* between authoritative and dialogic approaches as being an inevitable characteristic of meaning making interactions in science classrooms" (p. 606; emphasis in original). This tension arises because a good instructor, wishing to elicit students' initial ideas and involve students in active meaning making, will open the floor to student discussion. The researchers recognized the seeming futility of the open student dialogue, given the ultimate goal of indoctrinating students into the scientific worldview, but emphasized that in order for students' learning to be meaningful, they need to make connections between everyday understandings and scientific explanations. Drawing out and exploring students' ideas validates them and increases student motivation to learn and gain ownership of that learning; giving students space to try out the scientific discourse for themselves encourages them to make their own meanings.

Nevertheless, students are unlikely to arrive independently upon a scientific explanation of a phenomenon in the space of a class period; the authors noted, "The fact of the matter is that science is an authoritative discourse which offers a structured view of the world and it is not possible to appropriate the tools of scientific reasoning without guidance and assistance" (Scott, Mortimer & Aguiar, 2006, p. 622). Ultimately, the instructor will need to curtail free dialogue of students' ideas in order to focus attention on the accepted explanation; "[I]f students are to learn the social language of science, then somewhere within the teaching and learning performance there must be an authoritative introduction to the scientific point of view" (Mortimer & Scott, 2003, p. 106). This combination of tactics – opening the floor to student dialogue, then focusing the discussion to move it toward the scientific explanation – allows for "the direct juxtaposition of everyday and scientific views, and we [Scott, Mortimer & Aguiar] believe that this is of fundamental importance in supporting *meaningful* learning by students" (p. 617; emphasis in original).

Therefore, the researchers argued, teaching should be balanced between drawing out and elaborating upon students' ideas on the one hand, and helping move students toward incorporating scientific ideas on the other. They identified the following guidelines for science teachers (p. 613):

1. Opening up the problem;
2. Exploring and probing students' views;
3. Introducing and developing the scientific story;
4. Guiding students to work with scientific ideas and supporting internalization;
5. Guiding students to apply, and expand on the use of, the scientific view and handing over responsibility for its use;
6. Maintaining the development of the scientific story.

Arguments against an Authoritative Approach to Teaching Scientific Discourse

An opposite view is offered by Brown (2006) when he argued, “Despite the science community’s traditional view of communication in science as impersonal and content-based, the learning of science and its associated discourse reflects membership into an authoritative social framework” (p. 99). Like the scholars in the previous section, Brown also stressed the need for developing students’ scientific literacy, but with an emphasis on relating these skills to students’ identities in order to more seamlessly enculturate them into science. Brown focused on the cultural conflict that can arise for marginalized students during this enculturation process. In contrast to Fang (2005), Brown wrote, “Although [the discourse patterns and practices of science] are valuable in promoting student learning, these same discourse patterns also present limits to access for science learners as they stand at odds with those consistent with students’ normative discourse” (p. 98).

When identifying academically and identifying culturally are set up as two mutually exclusive paths, students must choose one and are forced to be marginalized from the other (Reyner & Jacobs, 2002; Monroe, 2002). This situation is particularly evident in science classrooms. Brandt (2008b) opined, “The territory encircled by the cultural borders of Eurocentric science provides a position of legitimacy, a location of credibility, and a place of power…I argue that scientific discourse is one way that borders are policed and maintained in the academy” (p. 838). Brown would agree; “Because science has an elite image, it has the potential to heighten students’ potential identity conflicts as they attempt to manage the tension between maintaining their identity and the identity of a science student. As language is invoked as a resource for signaling one's identity, the science classroom has the potential to be seen as a politically charged space where classroom language and participation reflects membership into cultural domains" (Brown, 2006, p. 98). Thus, the language of science teaching and learning is indicative of the adaptation of identities but also the site of identity conflicts.

Moje, Ciechanowski, Kramer, Ellis, Carrillo, and Collazo (2004) discussed a student who did not see any connection between the things she did in her free time, at home or elsewhere, and the things she was expected to do in science class. "Seeing these knowledges and Discourses as distinct made it unlikely that [the student] would often bring them to bear on others either in or out of school" (p. 59); in other words, despite learning about scientific discourse, the student was nevertheless not internalizing it nor using it in her life outside the space of the classroom. Similarly, Brown's (2006) study, for which he conducted focus groups with high school science students from minority groups, found that when asked about scientific thinking or problem-solving, the students tended to externalize these processes, attributing them to others (Scientists) rather than themselves. "Simply stated, when discussions regarding what constitutes a scientific perspective arose, students rarely considered themselves members in the community of scientific thought they were describing" (p. 113). The restrictive nature of scientific discourse proved to be a formidable challenge for the minority high school students in Brown's (2006) study. "Ultimately, students seemed compelled to distance themselves from science as it left little room for their identification through discourse." That is, students felt that the entrance into the scientific community required abandoning aspects of their identities, specifically those aspects defined by their discourse practices. According to Brown, “Such a notion implicates science discourse as a potential gatekeeper for students who attempt to assimilate into the culture of science” (p. 121).

According to Moje et al. (2004), “School texts [both printed and discursive] can act as colonizers, making only certain foreign or outside knowledges and Discourses valid” (Moje et al., 2004, p. 43), a notion reflective of the experience of Brandt’s (2008b) research participant, a Navajo college science student, who experienced conflict between her traditional beliefs and certain scientific stories she was learning. When these conflicts arose, she deferred to science intellectually (“It makes me feel, well, it must be true. They did all this work”) because she did not see any space for challenging the scientific stories, for instance with regard to the origin of species. Brandt recounted how the student referred to science as “a process of ‘belief’ rather than evaluating scientific data” (p. 835), so emotionally the matter was far from resolved. Later, Brandt included a quote from the student that explained how she resolved the issue to the best of her ability: “I’ll learn all I can. What I’m learning from my non-Navajo world will help my people health wise. But what I’ve been brought up with, it’s there. I’ll always believe my creation story” (p. 836). For some topics, the conflict between discourses was minimal or non-existent. But where her beliefs and her new knowledge were mutually inconsistent, the student had to compartmentalize the two in order to move forward in her studies. The student was told by her science instructors, explicitly and implicitly, that she would have to compromise something in order to be a successful in science; it was understood by the student that the “something” was her traditional worldview.

In response to this dilemma, Brandt wrote, "When Eurocentric science is presented as an ultimate truth with the strength of empirical data behind it, the language we use in our teaching reflects these ideas to the exclusion of students' lives and lived experience. Shifting our Discourse is one way to begin dismantling the cultural barriers that currently divides Eurocentric science from multicultural ways of knowing" (p. 842). Although, as Fang (2005), Mortimer and Scott (2003), and Scott, Mortimer and Aguiar (2006) argued, "tools for unpacking and strategies for revealing" meanings in scientific texts are necessary (Fang, 2005, p. 343), they are not sufficient, even if also eliciting students' discourses and knowledges; a critical perspective on how scientific discourse establishes and perpetuates status and power is also essential, particularly for those marginalized by the scientific community.

Power and Authority

"[A]ny discussion having to do with the improvement of subordinated students' academic standing is incomplete if it does not address those discriminatory school practices that lead to dehumanization" (Bartolomé, 1994, p. 176). Bartolomé argued that no pedagogical method is a silver bullet that will resolve the educational issues that non-mainstream students have in schools. If teachers fail to critically analyze the power structures of schools, how these power structures reproduce those of society, and the views of both schools and teachers about non-mainstream students, the patterns of failure with non-mainstream students will continue.

Bartolomé (1994) wrote of culturally-congruent pedagogies as promising, notwithstanding the fact that much of the related literature of the era failed to take into account the power differentials that were, in essence, normalized when the congruent practices replaced incongruent practices. Bartolomé argued that there is a political dimension to culture, because cultures are forged within political climates with varying degrees of status (Giroux, 1985). Thus, she concluded, culturally congruent teaching practices may be successful more because they promote egalitarian relations between the teacher and students in the classroom than because they match students' culturally-specific learning preferences. She wrote, "I believe that the specific teaching methods implemented by the teacher, in and of themselves, were not the significant factors [in students' success]. The actual strengths of methods depend, first and foremost, on the degree to which they embrace a humanizing pedagogy that values the students' background knowledge, culture, and life experiences, and creates learning contexts where power is shared by students and teachers" (p. 190).

Brandt (2008b) asked, "Can we imagine a pedagogy where some of that authority [of faculty members in the academy] is relinquished to permit students to speak and share their experiences of science within their own lives?" (p. 841). Engle and Conant (2002) referred to giving students authority as one of four principles (along with problematizing content, holding students accountable to others and to disciplinary norms, and providing relevant resources) for fostering productive disciplinary engagement. Giving students authority allows them to be "authors and produces of knowledge, with ownership over it, rather than mere consumers of it" (p. 404). In a similar vein, Patchen and Cox-Petersen (2008) discussed the notion of *affiliation* in culturally-relevant pedagogy, which "focuses on the ways in which teachers connect relationships developed in the classroom with realities outside the classroom, and how language is used to scaffold content and processing information. Extending beyond the classroom to the outside depends upon teachers and students developing real relationships, based upon mutual understanding and exposure to different perspectives" (p. 1007).

Bartolomé (1994) argued that this mutual respect demands of teachers that they challenge notions of "deficits" in the students that must be addressed, that they be open to learning about their students and viewing them as successful learners, and that they also be open to learning from their students. She wrote that a politically-informed educator can "create conditions that enable subordinated students to move from their usual passive position to one of active and critical engagement" (p. 177). Creating learning environments that support the success of non-mainstream students require teachers who "genuinely value and utilize students' existing knowledge bases in their teaching" (p. 182).

Funds of Knowledge

When given the opportunity, students draw upon their funds of knowledge, community-developed cultural knowledge specific to the survival of a particular people (Velez-Ibañez & Greenberg, 1992), when they interact with and seek to develop new learning. They also draw on their individual knowledge and experiences constructed and enriched over the course of their lives. Students' "totality of experiences, the cultural structuring of the households, whether related to work or play, whether they take place individually, with peers, or under the supervision of adults, helps constitute the funds of knowledge children bring to school" (Moll, Amanti, Neff & Gonzalez, 1992, p. 134). By the time students reach college, their knowledge resources are rich and deeply complex; whether acknowledged by the instructor or not, these funds of knowledge have a significant influence on what and how the students learn course material.

I imagine that if we could step into the mind of a student – or, alternatively, gain access to our own thought processes when we ourselves are learning something new – we would watch the construction of a striking web of meaning making through connections as, for instance, a physics student's mind visualizes the kinetic energy of the molecules in a gas; compares their motion to that of dancers at a *waila*; recalls visiting a dance club called Kinetic when he was in the city; wonders if the temperature of the gas increases when there are more molecules, like a dance floor heats up when there are more dancers; considers whether his analogy reveals something meaningful about the personality of the Universe or is merely a consequence of human pattern-seeking (something he learned about from a magazine article he read); remembers a conversation he had with his grandfather about *I'itoi'*s sense of humor; and sketches a mental picture of the diagram he'll make for his young niece to explain kinetic energy to her when he gets home. In the blink of an eye, a student creates a world and a context for new thoughts, grounded in any and all mental models, memories, philosophies, assumptions, and emotions that are triggered by his thinking, as well as any new ones that arise as a consequence.

Students' funds of knowledge develop through the interrelationships among the student and his/her family and community members. Family and community members know (and help co-create) the identity of the student within the context of this network of relationships, as compared to the teacher who primarily knows the individual only within the context of the classroom (Moll et al., 1992). The community interrelationships are described as “thick” by Vélez-Ibáñez and Greenberg (1992), as opposed to the classroom teacher/student relationship which is “thin”. With adult learners in a college classroom, the interrelationships are thin indeed, as instructors spend significantly less time with students in the college setting than do teachers in the school setting.

Moll et al. (1992) described teacher research that involved the teachers conducting ethnographic investigations into the homes of students in order to tap into the students’ and their families’ funds of knowledge. These funds of knowledge emphasized “strategic knowledge and related activities essential in households’ functioning, development, and well-being” and pertain to “the social, economic, and productive activities of people in a local region” (p. 139). The teachers’ familiarity with these funds of knowledge allowed them to create curricula that drew upon and extended the funds of knowledge.

Delving into students’ funds of knowledge is essential for understanding students’ cultural systems, which facilitates making connections to students’ cultural identities (Vélez-Ibáñez & Greenberg, 1992). Cajete (1988) advised instructors to draw content from Native students’ culture and experiences, grounding scientific concepts in what students already know about the world, incorporating cultural artifacts and community members as resources, and using students’ interests and concerns as jumping-off points to motivate students to learn about new topics in order to address salient issues in the community.

However, as discussed previously, instructors must also be wary of merely using the cultural knowledge as a step on the way to the content of Western science. As Kawagley and Barnhardt (1998) warned, students' cultural knowledge should not be exploited and then discarded for the sake of acquiring new knowledge that replaces the existing knowledge. Moll et al. (1992) distinguished between curricula grounded in students' funds of knowledge and what they called 'culture-sensitive curriculum' that relies more upon 'folkloric displays' of culture, primarily from the arts. Cultural relevance in the classroom capitalizes on students' cultural backgrounds and funds of knowledge, "rather than attempting to override or negate them" (Abdal-Haqq, 1994), and it should be a two-way street, where educators are also coming to understand students' points of view and the tribal worldview.

It is instructors' responsibility to employ students' funds of knowledge in creative ways in order to create culturally-relevant learning experiences. Gonzalez-Espada and Oliver (2002) discussed the opportunities in physics curriculum, often missed, to connect the content with local examples. Examples include using the ocean to discuss waves to students living in coastal areas, tribal instruments to discuss sound, local games to contextualize forces and motion, local architecture to discuss forces in structures, and local technology to highlight the use of simple machines. Basu (2006) proposed that two ways of engaging students' funds of knowledge in physics are project-based learning, in a more open-ended curriculum, and building research on students' interests into the pre-established curriculum, when that curriculum is less open-ended.

Another way to draw out the knowledge resources that students bring to the table is to create an atmosphere in the classroom where students' Discourses – ways of being, thinking, speaking, believing, etc. that comprise a collective identity within a community (Gee, 1996) – are given privileged status alongside the academic Discourse. A notable finding in a study by Moje et al. (2004) was the richness of the funds of knowledge that the students possessed, particularly those that could relate to the science content they were learning. "When students were explicitly asked to describe experiences, they did so with enthusiasm, but they had to be invited to talk about these experiences" (p. 64). Popular culture funds of knowledge were found to be very important to the students in Moje et al's study; in fact, the students "tended to draw on popular culture as much as, if not more than, they did their own experiences when discussing issues related to the science curricula under study" (p. 60). As a result of their analyses, Moje et al. (2004) expanded their category of "everyday funds of knowledge and Discourse" into four components: family, community, peer, and popular cultural.

However, though students were found to be actively creating connections on their own, as with linking popular culture funds of knowledge to the science content, they did not make these connections visible for the whole class (Moje et al., 2004). Thus, the researchers advocated for teachers' mindfully constructing space in the curriculum for building these connections, utilizing strategies such as listening to students, welcoming different funds of knowledge, and openly discussing biases in different texts to help students bridge experiences and scientific knowledge to create new meanings.

Balgopal, Wallace and Dahlberg (2012), who compared the ecological literacy of mainstream four-year college and tribal college biology students, cited Wickman and Östman (2002) for their recognition of the relationship between knowledge and emotions, stating that the latter "proposed a theoretical lens to study meaning making that assumes that learning occurs in social contexts when learners draw on both their cognitive and emotional understanding during classroom interactions. Likewise, we found that students needed to draw on both personal and cognitive funds of knowledge if they were able to demonstrate how they made meaning of ecological concepts" (Balgopal, Wallace, & Dahlberg, 2012, p. 84). Thus, not only does what students know affect their potential learning, but also how they feel about what they know, along with their emotional response to what they are learning.

Third Space

Just as simply eliciting students' prior knowledge is insufficient to support meaningful learning without a recognition of the status of such ideas, so too is simply incorporating students' funds of knowledge insufficient for creating a culturally-relevant classroom environment without sharing power with students and meeting them on their level. Moje, Collazo, Carrillo, and Marx (2001) described a case study of an instructor who, despite his attempts, was not able to connect students' Discourses with the science Discourse. Instead, this classroom was characterized primarily by competing Discourses; the instructor (Maestro Tomas) was able to connect Discourses when he "connected personally with the students' experiences," but had more difficulty "when he maintained the position of science teacher/science expert" (p. 479). As the researchers explained, "Despite the best efforts of the research and development team (which included Maestro Tomas), the students and Maestro Tomas often used the same words, but talked, read, and wrote across each other" (p. 476). This difficulty seems to have stemmed from the teacher's "struggle to bridge the competing Discourses at work in his life, those of science teacher, scientists, and Latino" (p. 479), including the scientific Discourse and the Discourse of the project-based, constructivist pedagogy the curriculum called for. The researchers identified issues with the curriculum itself, in that the driving question matched neither students' preferred Discourse, nor was it a true representation of scientific Discourse. In general, the teacher and curriculum elicited students' Discourses, but privileged the scientific Discourse without taking the opportunity to scaffold from the everyday to scientific Discourse. As well, the researchers reported that opportunities to draw in students' everyday Discourses were missed by the teacher.

The case described above is an oft-cited counterexample of a construct known as *third space*. Gutiérrez et al. characterize the third space as a zone of development (Vygotsky, 1978) where existing knowledge can be scaffolded to new hybrid knowledge that takes from all shared perspectives. Third space has been characterized in the literature as an environment which:

1) is a result of the discourse of people coming together to challenge, redefine and reclaim the signs and symbols of a culture, in particular a dominating culture (Bhabha, 1994);
2) brings together Discourses from different communities and blends them together to create new ideas and understandings (Soja, 1996);

3) is a means of mediating students' Discourses as resources for developing academic understandings of the world (Gutiérrez, Baquedano-López, Alvarez, and Chiu, 1999); and
4) is a means of bridging diverse Discourses so that students may identify similarities and differences across Discourses, for the purpose of challenging existing knowledge systems and creating new ones (Moje, Ciechanowski, Kramer, Ellis, Carrillo, and Collazo, 2004).

Gutiérrez, Rymes and Larson (1995) defined third space as the intersection of the official and unofficial social spaces of the classroom, where the *script* of the teacher in the latter[1] and the *counterscript* of the students in the former come together to share both the space and the power. In the third space, no one single voice has a higher or lower status than the others, which is contrary to the typical teacher-centered classroom where the teacher's script is dominant and the students' resulting counterscript is marginalized. "In the face of a seemingly incontestable teacher script, students assert forms of local knowledge that are neither recognized nor included within the teacher script. In this context, such forms of knowledge include unacknowledged cultural references to popular music, film, and television" (p. 451). The authors argued that the third space is where the student and teacher worlds merge as they negotiate what knowledge is valuable and who, ultimately, has the power to create it. The creation of the third space disrupts the power differential of the traditional classroom. A transformative dialogue can only take place

[1] What are referred to as official script and counterscript by Gutiérrez, Rymes and Larson (1995) are concepts parallel to "everyday Discourses" and "scientific Discourse" in the Moje et al. piece (2001, p. 487).

when the teacher not only makes space for student voice but also provides students with "opportunities to elaborate on and incorporate their own narratives into the larger classroom text" (p. 453).

Moje et al. (2004) argued that third space can result in fragmentation and angst if students are constantly reshaping their identities in opposition to the dominant Discourse, rather than reshaping the Discourse by integrating across different funds of knowledge. The teacher's role, as well as the students', is to "incorporate divergent texts in the hope of generating new knowledges and Discourses" (p. 43). As well, "The goal of constructing third space is not to teach youth that academic or everyday funds are more right or more wrong but simply to make a space for multiple forms of knowledges and Discourses in the interpretation of classroom texts" (Moje et al., 2004, p. 55).

Moje et al. (2001) recognized that third spaces in the classroom can only be constructed when the walls separating the classroom and the community are broken down. Walls between the instructor and the students, and between the content and the students, must also be deconstructed. Gutiérrez, et al. (1995) wrote, "It is within this third space that students and teachers can bridge the various social spaces within classrooms. This bridge creates the potential to rewrite and contest extant texts and discursive practices. It becomes possible for both teacher and student to redefine what counts as knowledge" (p. 467). Similarly from Moje et al. (2004), the third space is where "everyday resources are integrated with disciplinary learning to construct new texts and new literacy practices, ones that merge the different aspects of knowledge and ways of knowing offered in a variety of different spaces" (p. 44). Moje et al. defined third space as the merging of "knowledges and Discourses drawn from different spaces" (p. 41), i.e. home and community spaces with formal spaces like school and work. Lipka, Sharp, Adams and Sharp (2007) related Gee's (1996) concept of borderlands to third space: borderlands where two cultures or language meet, interact and evolve into something new are a third space of cultures. Classrooms, the authors argued, are potential cultural third spaces, a blend of influences from the mainstream and local cultures. "These third spaces have the potential to become productive uncharted zones between school and local cultural knowledge and norms" (p. 97).

Consciously building third space requires access to students' funds of knowledge on the part of the instructor. Moje et al. (2001) recommended eliciting students' knowledge about something that interested them, and using that knowledge and interest to tie to curricular activities that build upon them. They also suggested linking the personal/local to the global/universal, expanding on personal experience to discuss broader themes. Similarly, Moje, et al. (2004) wrote, "Building bridges is a necessary part of what makes third space because it helps learners see connections, as well as contradictions, between the ways they know the world and the ways others know the world…[A] third space focused on cultural, social, and epistemological change…is one in which everyday resources are integrated with disciplinary learning to construct new texts and new literacy practices, ones that merge the different aspects of knowledge and ways of knowing offered in a variety of different spaces" (p. 44).

The creation of third space involves utilizing different registers of discourse (e.g. formal and informal), sharing power (e.g. allowing students' questions and interests to drive an investigation and/or shape the curriculum), incorporating student innovations (such as students' connections between content and personal knowledge) and incorporating personal experience and narrative (Gutiérrez et al., 1999a). Wrestling to reconcile disparate identities, motivations, perspectives and values leads to unpredictable new understandings negotiated among the group, which are rich and grounded in the context of the collective class experience.

Mortimer and Scott (2003) would argue that a collective understanding is impossible, as each individual has their own personal understanding. "Such interventions [by the teacher], to review and summarize progress, are often talked through by the teacher in a 'we' voice…The implication of the 'we' is that there is a shared understanding…within the class of the scientific story at that point. Of course, it is clear that this can never be the case, given the individual reconstructive step in learning" (p. 71). Others would argue that it is not so clear; though each individual is only privy to their own minds, the class as a whole can share understandings and, by so doing, co-create new ones. As well, Indigenous researchers would argue that all knowledge is collectively shared (Bishop, 2008; Wilson, 2008; Kovach, 2009). "Knowledge is shared with all creation…It is with the cosmos; it is with the animals, with the plants, with the earth that we share this knowledge" (Steinhauer, 2002, p. 177).

Hybridity

Gutiérrez, Baquedano-López, and Tejada (1999a) defined hybridity as a multitude of voices, perspectives, and context that often results in tension and conflict, but such conflict, rather than being divisive and negative, can serve as the impetus for new growth and learning. Nelson-Barber and Estrin (1995a) wrote, "When essentially different approaches to knowledge come in contact with one another, they may conflict or collide, or they may complement each other….In some ways, this case is similar to the experience of speaking more than one language: Learning a second language gives perspective on the first, expands one's notion of language, and makes for greater cognitive flexibility, if one is supported to maintain the first language and if respect is accorded to that language" (Nelson-Barber & Estrin, 1995a, p. 178). Gutiérrez, Baquedano-López and Tejada (1999) elaborated on the idea of tension as characteristic to third spaces, as well as hybridity and diversity, which "are not problematic but rather are viewed as important cultural resources in children's development…Hybridity and diversity serves as the building blocks of Third Spaces" (p. 287). According to Gutiérrez et al. (1995), "It is precisely this tension – this relationship between script and counterscript or this juxtaposition of relative perspectives involving struggle among competing voices – that creates and maintains the third space" (p. 467).

The role of the non-Native instructor as a source of diversity in the classroom discourse is valuable; Gutiérrez et al. referred to this diversity as a resource from which the individuals in the class, as well as the class as a collective, can draw; that is, "alternate and competing discourses and positioning transform conflict and difference into rich zones of collaboration and learning" (p. 286). Thus, while the lack of understanding of the tribal perspective is a definite disadvantage for non-Native instructors who are striving for cultural relevance, the struggle for understanding on the part of each individual in the classroom can be a fertile ground for new co-constructed knowledge in the third space. Using Native culture as a bridge to conventional curriculum leads to a broader understanding of both. The culture brings in the standard curriculum through common threads. The curriculum can use a combination of cultural content (learning language and culture to maintain American Indian identity) and bicultural education (learning the conventional curriculum via a cultural understanding). Agbo (2001) calls this a “cross-fertilization of Native American and the dominant American cultures” (page 44). However, Moje et al. (2001) were cautious about the need for border crossing and deconstruction, lest blurring the lines between home and community settings and the classroom setting invade upon students’ privacy.

Hybridity in Science

Ogawa (1995) asked, “While cultural diversity claims that culture should be viewed in a relativistic perspective, why is science itself never viewed in such a relativistic perspective?” (p. 584). Ogawa advocated for multiscience teaching, in which students are made aware of their personal science (what they’ve observed and believe about nature) and their indigenous science (cultural beliefs about the world, i.e. their cosmology), as they are learning mainstream Western science, which represents only one of the many sciences that humans have created throughout our history. Ogawa would agree with Ogunniyi (1988), who wrote that individuals can hold and understand different explanations of scientific phenomena at the same time, and can choose for themselves how they see the nature of the phenomenon. For instance, as Ogunniyi suggested, a Christian Western scientist may give credence to both Biblical and scientific explanations of phenomena.

"[L]earning science involves developing an alternative way of talking and thinking about the natural world. It involves learning the social language of school science and adding it to a personal 'toolkit' of ways of talking and knowing about the world, which can be drawn upon as appropriate, in different contexts" (Mortimer & Scott, 2003, p. 94). Mortimer and Scott did not consider this to be an issue that needs resolving, but they did believe it was a something that students should be made aware of – there may be valid everyday ways of understanding something *and* scientific ways of understanding it, and one does not need to replace the other. They can coexist, to be invoked whenever needed. The researchers contended that while it is challenging for both the students and the instructor to wrestle with conflicting views of nature, "we would strongly maintain that it is precisely at these moments, when the dialogicality of the meaning making process (with views being placed alongside each other) is most evident, that there is the greatest chance of significant learning occurring" (p. 98). This argument is aligned with the notion of tension and hybridity in the third space.

Mortimer and Scott (2003) argued for "the importance of providing opportunities for students to *talk their way* into the science story" (p. 98, emphasis in original), a notion which appears to take an assimilative approach, but their goals for this perspective hint at hybridity. "By allowing these opportunities to talk through the science and to relate it to everyday views, we believe that there is a greater chance of students mastering the scientific perspective and *making it their own*" (p. 99, emphasis added). Similarly, Aguiar, Mortimer and Scott (2010) argued that students "need to engage in the dialogic process of exploring and working on ideas, with a high level of interanimation [i.e.

consideration of multiple voices], within the context of the scientific point of view" (p. 178). Mortimer and Scott (2003) noted that in both cases in their study, students were enthusiastic about the science lessons because, they posited, students' voices were heard and valued, and students recognized "that there was room for dialogue between their points of view and the scientific view" (p. 116).

Moje et al. (2001) encouraged instructors to build students' metadiscursive awareness by being "explicit about the different Discourses at work in the classroom, teaching students, for example, how the language of science is often different from the language of everyday even when the same words are used" (p. 491). This, they posited, would help students build critical literacy, where they are aware of how to engage different Discourses and how different Discourses afford participants different power and status, as well as scientific literacy, where they both "learn skills for making sense of scientific Discourses while also constructing new knowledge that represents an integration of their experiences with those findings and theories generated in scientific discourse communities" (p. 492). Moje et al. (2004) suggested that when teachers make space for students to offer their perspectives and experiences related to school science learning, they not only have the opportunity to extend the conversation around the content – linking everyday observations and activities to formal science practice, demystifying science and showing the connections between everyday and science Discourses – but also to show students that their knowledge is valued and valid.

"It is through students comparing and contrasting their views with the scientific one that they can begin to make sense of the scientific story being taught. Arguing more broadly, if school science is to prepare students to be citizens who are critically aware of the different perspectives that are at issue when a societal problem has a scientific component, then the science taught in school must be related to common-sense, everyday views. The only way this can be achieved is through dialogue, which results in students enlarging their already heterogeneous cultural views, with science offering one more perspective to be added to the 'toolkit' that students can draw upon" (Mortimer & Scott, 2003, p. 106). Mortimer and Scott related their conception of students' movement from "everyday" plus "scientific" discourses, toward an expanded toolkit including both, to Bakhtin's (1934) notion of progressive appropriation of meanings, from introduction of new ideas by others, to students seeing the idea as half their own and half others', to students seeing the idea as completely their own.

Aikenhead and Jegede (1999) identified two possible approaches to resolving conflicts between different knowledges: a holistic worldview versus a pluralistic worldview. With a holistic worldview, different knowledges are integrated as different facets of a unified whole, drawing upon secured collateral learning. A pluralistic worldview, or what Aikenhead and Jegede referred to as "multiple views of the world" (p. 283), compartmentalizes different knowledges via parallel collateral learning. Either approach can lead to successful border crossing. Cajete (1999b, p. 146) wrote:

> [O]ne often finds a mixture of observations based upon combinations of folk, experiential, and school-derived sources. Such observations may appear to be contradictory, and a teacher might wonder how these disparate combinations of ideas about nature can be comfortably accommodated within a single student's understanding

> of the world. To a non-Native American observer, this mixture of perspectives may seem to be a paradox that must be reconciled…This conditioning of students to think in only one way regarding the explanation of natural phenomena is a key concern in enhancing creative scientific thinking because such conditioning eventually stifles creative learning.

This idea supports the value of secured collateral learning with a pluralistic worldview; it is not necessarily a problem for students to hold contrasting ideas about the natural world, if the students have confronted and resolved any conflicts to their own satisfaction, and in Cajete's perspective, holding a diversity of ideas is actually an asset for the synthesis of new ideas.

Brandt's (2008b) case study of a Navajo undergraduate student and her encounters with Western (Eurocentric, in Brandt's parlance) science focused on how this student struggled to reconcile scientific discourse with the existing Discourses in her life, such as the Navajo creation narrative. As a science advisor, Brandt argued that "our current use of scientific discourse assimilates students into the values of Eurocentric sciences to the exclusion of other ways of knowing, a process which is uprooting, and mired by confusion and anxiety." She concluded, "In our effort toward equity in science, I advocate expanding our notion of discourse beyond mere talk or writing to include values, behaviors, and ways of being" (p. 827).

Ray Barnhardt (in Brandt, 2008a) wrote, "I would argue that it is possible to bring the study of Euro-scientific knowledge and the traditional knowledge of Indigenous peoples together in a way that deepens our understanding of both, and gives students an opportunity to deepen their own sense of self in the process" (p. 725). Not only does hybridity in the science classroom result in better understandings of existing knowledges, as well as new understandings that arise when these knowledges interact, it is also supportive of students' identities. Building a third space drawn upon a hybridity of knowledges allows students to position themselves and gain not only content knowledge but self-knowledge as well.

Creating Third Space in the Science Classroom

Gutiérrez, Rymes and Larson (1995) identified effective communities of practice in their research: "classroom communities whose participants construct classroom life within this third space" (p. 468). They described these classrooms as egalitarian, privileging the voices of all participants; the teachers drew upon students' funds of knowledge to "transform what counts as learning."

Moje, Collazo, Carrillo and Marx (2001) studied third space as it arose in the discourse around project-based science in a seventh-grade science class. The authors identified three (out of potentially many) Discourses salient in a classroom: disciplinary or content area, classroom, and social or everyday Discourses (p. 471). As with any Discourses, these can intersect with the potential of overlapping or conflicting. Moje et al. laid out four characteristics of classroom interaction that appeared to be necessary for developing third space in science classrooms (p. 489):

a) drawing from students' everyday Discourses and knowledges,
b) developing students' awareness of those various Discourses and knowledges,
c) connecting these everyday knowledges and Discourses with the science discourse genre of science classrooms and of the science community, and

d) negotiating understanding of both Discourses and knowledges so that they not only inform the other, but also merge to construct a new kind of discourse and knowledge.

Gutiérrez, Baquedano-López and Tejada (1999) reported, in their case study of a classroom where they saw third space being used productively, that the classroom community was inclusive of student behaviors and speech that would be considered unsuitable in other classrooms. “Talk, interaction, reading, writing, and sharing in a variety of codes and registers here were considered the means to productive learning. Moreover, the teacher and the children placed a high value on respecting the language, social practices, and beliefs of the classroom community and its individual members” (p. 291). Differences in the classroom were not only respected but valued for their potential for learning. In the case study classroom, one student insulting another led to a teacher intervention to discuss insults, which led the class to a spontaneous discussion about, and ultimately a whole unit on, human reproduction, which was not a part of the formal curriculum. In the course of this unit, the teacher drew in students’ colloquial language, impromptu descriptions, and even their emotions (nervousness and laughter) and incorporated them into the broader classroom community, meeting the students in the third space. Students’ counterscript became, as the authors showed, “an occasion for meaning-making” and “effective sense-making practice” (p. 298). Five practices were identified as occurring in the third space of this classroom (p. 301):

a) conflict leading to shared and negotiated understandings,

b) drawing parallels between home and academic lexicons,

c) hybrid language practices (both English and Spanish),

d) hybrid speech genres and use of humor, and

e) rekeying of teacher/student scripts as resources for learning.

The researchers discussed how the hybridity in the classroom was “actively mined” by the students and the instructor and used strategically to bridge home and classroom knowledges and to create new “contexts of development” (p. 291).

Calabrese Barton, Tan and Rivet (2008) related how their student participants engaged with science in ways that supported their identities as well as their science learning and, in some cases, offered them opportunities to increase their social status. The hybrid spaces the students constructed “brought together sanctioned and unsanctioned resources and identities in novel ways that supported who the girls were and wanted to be, extended their participation in school science, and transformed their learning communities” (p. 93). The researchers identified these hybrid spaces as third spaces because they integrated the students’ social identities and the scientific Discourse, “making the boundaries between these worlds porous and movement between these worlds fluid” (p. 95). In these spaces, the students’ authority increases, as they take on the role of experts, and the instructor’s authority is reduced as it is shared.

“We see these hybrid spaces as moments where science is no longer a separate world as students learned to display competent and meaningful scientific literacy in applying scientific knowledge to their local communities and their daily living” (Calabrese Barton, Tan & Rivet, 2008, p. 70). The hybridity that the participant students constructed had an effect on the physical space of the classroom, where students modified the physical space to reflect familiar out-of-school spaces, the politics of the classroom, where students became experts with power and authority, and the pedagogy of the classroom, where the students were involved in co-constructing the curriculum.

Lipka, Sharp, Adams, and Sharp (2007) described the creation of third space in a Yupiaq elementary math classroom where the topic was geometric shapes, patterns, and the relationship between the two. The third space was created through the melding of local and mainstream pedagogies, vocabularies, values, and content knowledge; "this cultural and linguistically-based activity of pattern making and the module's emphasis on geometrical relationships creates an integral and authentic connection between the mathematics and social-cultural norms embedded within Yupiaq culture and language and school-based mathematics" (p. 111). In an earlier article, Lipka et al. (2005) described how the curriculum-relevant math curriculum was itself a factor in creating third space in the classroom (p. 369-370):

> Through the culturally based math modules, the connections to students' experiences and prior knowledge that originate and often reside outside of the traditional school curriculum are brought into dialogue with the academic content knowledge taught in school…We suggest that the culturally based curriculum creates a 'third space' in which this dialogue takes place. Equally important, the notion of third space refers to the opening up of a place in which historically silenced knowledge of Indigenous peoples such as the Yup'ik is privileged alongside traditional academic discourses. Thus, culturally based education, as a third space, creates possibilities for social and

epistemological change such that knowledge and discourse, which have traditionally been in tension with one another, are brought together" to result in potential changes to both.

Lipka et al. (2007) explained how what happened in the classroom was not an exact analog of what you would see in the community, nor what you would see in a mainstream classroom, but rather a unique blend of activities and language that were "creatively adapted by [the teacher] to fit the dual goals of teaching in a Western institution (schooling) yet transmitting Yupiaq language and culture."

Brandt (2008a) highlighted the importance of physical space to construct discursive spaces: comfort zones, both literally and figuratively. For one of her participants (an Indigenous medical student), "a comfort zone represented discursive spaces where she and other Indigenous students could be at ease, and interact without having to explain themselves, knowing that they shared a similar worldview" (p. 713). Faculty members who created such spaces in their classrooms were respected by the Indigenous students. The students appreciated faculty members who wanted to create dialogues with students, who could contextualize the science within familiar frames of reference, and who brought their own and students' life experiences into the classroom. Brandt referred to these classroom discursive spaces as *locations of possibility* – "those discursive spaces in which students and their instructors value connected knowing, acknowledge each other's history, culture and knowledge. In this space, instructors and students begin speaking to each other subject-to-subject, and they challenge normative views of schooling…By creating discursive spaces in which narratives can be shared on the university campus, scientific discourse becomes expansive rather than narrow, boundless instead of limited, and inclusive rather than exclusionary" (p. 718-719).

In the Forum that discusses Brandt's (2008a) article, Deborah Tippins expanded on the notion of locations of possibility. "Perhaps another way to think about these locations of possibility is to consider them as communities of identities-in-relation-to. In other words, can we learn about cultural narratives such as the 'Euro' stories and the TEK [traditional ecological knowledge] stories together in relation to enhance the creative expressions of the sciences? Aren't the locations of possibility just places where this occurs?" (p. 724). Tippins conceptualized Brandt's locations of possibility as third spaces where new relationships lead to creative new understandings of science. Ray Barnhardt further connected locations of possibility to third space: "If we can stand back and approach the different forms of knowledge and ways of knowing with an understanding that each has its own integrity, then we can help students construct a 'third way' of knowing at the level of what happens when different knowledge systems interact" (p. 725). This selection from Deborah Tippins explains how such a third space can benefit students (p. 726):

> If we think of all knowledge as narrative, then science is the representation of many different stories about the world. In this sense, students in Carol [Brandt]'s study will hear many different stories from their scientist-teachers ranging from 'this is the way it is' to 'this was my story year's [sic] ago and here is how it has changed.' In the process, they may ask themselves, 'If my story is not right then whose story is right?' Throughout her study Carol describes locations of 'singular' possibility. But perhaps these locations

of possibility might better be described as locations of possibilities (plural) where students come together to study science (minus the 'Euro') and learn their teachers' stories, which may or may not reflect their stories. Along the way they can make decisions such as the teacher's story is not my story, and my story is more legitimate than that of my teacher. I think it is useful to think of locations of possibilities (plural) in order to emphasize that science is always many stories-in-relation that are changing, complex, and laden with uncertainty. It is these locations of possibilities that can provide students with the opportunity to tell their own stories, and in so doing reinforce the significance of cultural and ecological pluralism.

Brandt's (2008b) article described how a place for discussion can promote Native science students' socialization into the scientific Discourse, and ultimately their success. The place referred to in Brandt's article was a research experience, where students could practice using scientific Discourse and ask questions outside the classroom. The research staff used both scientific Discourse and a modified version of this Discourse, allowing students access to the Discourse community and scaffolding their understandings. The student in Brandt's study described how one of the research staff had joked that, "We scientists like to use all these words that other people can't understand" (p. 835) – usage of this specialized jargon identifies the speakers as members of the scientific Discourse community, and by extension marks those that "can't understand" the jargon as outside the community. Two of Brandt's (2008a) participants created discursive spaces within their academic writing, "blending scientific concepts with Indigenous thought through their use of examples from daily life and traditional Navajo belief" (p. 714). Brandt saw the students' use of their own voice, perspectives, and experiences in their writing as evidence of the students' self-identification with science.

Conclusion and contribution of this study

This chapter summarized the literature that has contributed to the construction of a conceptual framework for this study, including literature on the characteristics of Native students; the importance and tenets of cultural relevance, especially for Native students in science; and Discourse as a lens for understanding border crossing, science discourse, funds of knowledge, hybridity and the construction of third space. The present study extends the literature to the tribal college science classroom, where the learners are adults, the age discrepancy between them and the instructor is smaller, and their funds of knowledge are broader and more complex. These rich funds of knowledge and the autonomy of the learners increase the potential for hybridity in a third space, so long as the instructor is mindful to allow for such spaces.

The research described here supports the cultural relevance theorists' supposition that culturally-relevant curricula support students' meaning making around new learning while supporting their identities. The literature on third space and hybridity propose a framework for explaining what factors of cultural relevance specifically achieve those goals, such as the inclusion of students' voices in the classroom, ethical and moral considerations of the content, and a critical approach to teaching about science discourse and its associated power.

The present study draws on these analytical lenses and their findings to contextualize an investigation into the meaning making around the content of introductory physics by tribal college science students. For the purposes of this study, meaning making is defined as the creation of a conceptual map of a construct, either individually or collectively, that is personally meaningful to those who construct it. Meaning making is putting a concept, such as gravity, into a personally-meaningful context.

This study builds upon research on Native students' successes in the college environment and extends them to the classroom, using an in-depth qualitative approach influenced by Indigenous methodologies to explore how the meanings that students assigned to the content are evident in their classroom dialogues. The context of the study and the methodology used for data collection and analysis are described in the following chapter.

CHAPTER 3: METHODS

Overview

What follows is the story of how this project came to be, including an explanation of why it must be told as a story. In this chapter, I describe the methodology employed by this study, including the qualitative and Indigenous research methodologies used to inform decision-making about the research, the context of the study, the data sources, and the analysis process. This was a case study focused on one introductory physics class at Tohono O'odham Community College in Sells, Arizona, offered in the Spring semester of 2008. The research participants were the students of the course, and I was their instructor. I had developed the curriculum for this course with an emphasis on cultural relevance, with input from members of the Tohono O'odham community as well as from educators at other institutions.

The purpose of the study was to examine how the students made meaning from the course content during the curriculum's enactment over the course of the semester, with an emphasis on the connections that students made between the content and their personal and cultural backgrounds. Data collection consisted of audio recordings of class sessions, and reflective journaling composed by me, primarily after but occasionally during class sessions. The analysis of the data was used to address the following research question:

Within the context of a physics course designed to be culturally relevant, how did students make meaning of physical concepts through dialogue?

In the sections below, I describe my positionality, an overview of qualitative and Indigenous methodologies, the process of obtaining approvals for the research from both the university and the tribal college, the contributors to and decisions made about the course, a description of the resulting course, an overview of the data collection procedures, and finally an account of the data analysis.

Researcher positionality

As a White graduate student of science education, it had never occurred to me to consider culture and ethnicity as influential in student learning, until they became influential in my teaching. Early in my graduate career, I was introduced to a Lakota community through a professional contact, who invited me to offer a science learning experience for the community's students. My professional contact, who over the years became a dear friend, was like an open doorway: come see what the world can be outside of your comfort zone; come hear what we have to say; come learn how to help our children learn. When I went with him and brought my little science activity for the kids, as silly as it was in retrospect, I was walking through this open doorway and responding: I am willing to learn. I witnessed first-hand the inequities in educational opportunities and achievement among these students, and was out of my element. I observed these things from the outside looking in, because my educational background had been so privileged. Nevertheless, I was so intrigued by what I saw as the missed opportunities to engage under-served students that I persisted in studying the inequities and opportunities of minority student education. My experience with this Lakota community, my interactions with the community that continued as I returned on a yearly basis, and similar experiences with different Native communities, were the stepping stones to my choice to pursue a minor in American Indian education, and my focus on contributing to the little corner of it, science education, where I thought I could be of most use.

I had a wonderful mentor in Dr. Robert Martin when I was first attempting to make a go at being an independent education researcher. The former president of TOCC, he saw how my ideas and the college could benefit from one another, and he helped pave the way for me by introducing me to the then-current president of the college and setting up dialogues between us about what the college needed, and how I could offer something to fulfill that need in return for collecting data on what I tried. I had my heart set on offering an astronomy course grounded in Tohono O'odham culture, even though at the time I had only a cursory understanding of what "Tohono O'odham culture" meant. But the college needed physics, so that was the course I stepped in to offer. Because my background in physics was a lot weaker than my background in astronomy, this shift required me to go even further outside my comfort zone and seek out further resources in people and curricula.

As it happened, the course I offered to teach has special meaning to me, being the course that got me started on my career path when I was a young student. When I took the equivalent of this course, introductory physics, in my senior year of high school, the experience I had in the class convinced me to continue in physics when I got to college. Taking physics, and later astronomy, in college made me realize how much I enjoyed science – a subject I'd always hated! – and I went on to major in astrophysics and begin a career in astronomy. The love of the fields of physics and astronomy that I'd discovered was thanks in no small part to the wonderful teachers and learning experiences I'd had in my late adolescence, and it was to honor and share their profound influence that I decided to go into science education myself, perhaps to inspire other students as I had been inspired.

When I started out with this research, I approached it in a fairly standard way: establish the existence of a problem; propose a solution to the problem. I shifted the focus when I became aware that it wasn't necessary to do everything in the traditional manner. Of course any number of problems would become apparent if you begin with an expectation of finding them, but I didn't want my dissertation to start out with such a negative expectation. Rather, I wanted to highlight positive efforts that are going in American Indian education and contribute to those efforts. I chose the topic because I felt that something positive could be done for tribal college students in science education, and because tribal colleges have the specific mission of making their curriculum relevant to their students.

I believe that, among other things, Native students have a right to learn about their scientific heritage, to help them extend their cultural pride to their cultures' scientific understandings as well as to help them fend off the damage that can be caused by the effects of mainstream society. I felt that developing a culturally-relevant science curriculum for the students could be a solution. I began this research project thinking I would develop a piece of science curriculum, try it out, and see how it went, but naturally the story took a turn for the more nuanced and less calculated when it was actually in progress. As the semester unfolded, I realized that what I was doing was not *for* my students, but *with* them. I was struck by my students' ingenuity that cropped up in unexpected instances, when they were given the chance to express it. The importance of this echoes my colleague-turned-friend’s message: just as much as I was there at the college to teach, I was there to learn, and I had to listen to what my students were telling me before I found the real story to be told by this research. Numerous stories could have emerged from this experience, but the one told in this dissertation is the one that emerged for me and through me.

Qualitative and Indigenous methodologies

This study employed qualitative and Indigenous methodologies in its structure, data collection procedures, and analysis. Qualitative and Indigenous methodologies have many similarities and shared interests, such as an emphasis on holism, and developing understanding through creating a detailed picture of a phenomenon, whether through narrative, performance, visual arts, or whatever medium will best tell the story. Like Native storytelling, Indigenous research is artful, compelling, human-oriented and imbued with lessons. It takes form from the touch of the researcher and lives through the reader, not unlike qualitative research, which has been described as carrying its meaning “in its entire text” (Richardson & St. Pierre, 2005). As with written works produced from Indigenous methodologies, “Qualitative research has to be read, not scanned; its meaning is in the reading” (p. 960).

Kovach (2009) compared and contrasted qualitative and Indigenous methodologies, stating that “both approaches are relational” and that “both approaches must show evidence of process and content” (p. 32). In Kovach’s work, she presented a diagram representing the relationships between qualitative and indigenous methodologies. Qualitative methodologies were represented by a rectangle and Indigenous methodologies by an oval. The two shapes overlapped but were separate; neither was subsumed by the other. Wilson (2008) described one difference between the two approaches being in the way they analyze data: "In analysis through an Indigenous paradigm, accuracy does not play as big a part in describing the phenomenon but is more important in describing the set of relationships that make up the phenomenon. The ideas or concepts are thus encircled [rather than the Western concept, triangulated] with an entire set of relationships" (p. 122). Wilson characterized Guba and Lincoln's (2005) classification of dominant paradigms – positivism, post-positivism, critical theory, constructivism, and participatory/cooperative: "knowledge is seen as being *individual* in nature." Wilson contrasted this epistemology with that of the Indigenous paradigm, "where knowledge is seen as belonging to the cosmos of which we are a part and where researchers are only the interpreters of this knowledge" (p. 38).

Given that I was interested in investigating the meaning making that students enacted in the classroom setting, a qualitative methodology was fitting; Denzin and Lincoln (2005b) emphasized that qualitative researchers seek understandings of "*how* social experience is created and given meaning" (p. 10, italics in original). According to Denzin and Lincoln, "Qualitative research is a situated activity that locates the observer in the world. It consists of a set of interpretive, material practices that make the world visible…This means that qualitative researchers study things in their natural settings, attempting to make sense of, or interpret, phenomena in terms of the meanings people bring to them" (Denzin & Lincoln, 2005b, p. 3). As well, the researchers noted, "Of course, all settings are natural – that is, places where everyday experiences take place" (p. 27). Denzin and Lincoln described qualitative researchers as *bricoleurs*, or quilt-makers, who piece together representations to create a whole.

As a qualitative researcher, I stressed the socially-constructed nature of reality both in the classroom and in my research. In the latter, we challenged the notion of science as truth and focused instead on the meaning of scientific knowledge for the members of the class; in the former, I focused on how the students made meaning of the content through the socially constructed dialogues. This research is an intrinsic case study (Stake, 2005), in that I was interested in this one particular case – one single semester of one single class – not for the sake of generalizing it to other cases, but for the sake of gaining a deep understanding of this one case. Where exactly the class ended and the rest of its members' lives began is not a firm boundary, as the class and our lives were reciprocally influential, yet the case itself is bounded in time, place and purpose.

This research was conducted under the auspices of a tribal college, with Native students, and with the intention of benefitting educators of Native students in tribal colleges and elsewhere. For these reasons, elements of Indigenous methodologies, influencing for instance the research protocol, the emphasis for the analysis, and the tone of the narrative, were incorporated in an effort to develop a study, and create a written product related to the study, that would be respectful, meaningful and useful to this population.

However, this study does not truly represent Indigenous methodologies, as it does not emerge from an Indigenous epistemology (Kovach, 2009). Under an Indigenous paradigm, rather than focusing on co-created meanings developed in a third space between students and instructor, this study may have emphasized collective interpretations developed in a third space between the members of the class and the cosmos. Instead, the study is a blend of Western-oriented qualitative and Indigenous methodologies, and is situated in a third space in which these methodologies interact (Likpa et al., 2005). “Researchers wishing to use Indigenous inquiry may use it alongside a Western approach that organizes data differently (e.g., grounded theory, phenomenology), thereby using a mixed-method approach. The data can be coded, emergent themes groups and bracketed, and so forth, while transparently indicating that it is not an Indigenous epistemological approach to data analysis” (Kovach, 2009, p. 35). This is precisely the case for this work, for which data were analyzed qualitatively, though I make an effort in the following chapter to present the results in a manner more consistent with an Indigenous approach.

Because Indigenous research is a developing field, and because I myself am non-Indigenous, an overview of Indigenous methodologies and an explanation of why I chose to make use of them follows.

Overview of Indigenous Methodologies

Kenny (2000) defined Indigenous research as that which “reflects the values and beliefs of our peoples” (p. 144-145). Similarly, Evans, Hole, Berg, Hutchinson and Sookraj (2009) wrote that Indigenous methodologies are “research by and for Indigenous peoples, using techniques and methods drawn from the traditions and knowledges of those peoples” (p. 894). Kovach (2009) would agree; she included four ethical considerations for Indigenous research (p. 48): (a) that the research methodology be in line with Indigenous values; (b) that there is some form of community accountability; (c) that the research gives back to and benefits the community in some manner; and (d) that the research is an ally and will not do harm. Atkinson (2001) developed a more comprehensive list of principles (p. 10):

- Aboriginal people themselves approve the research and the research methods;
- A knowledge and consideration of community and the diversity and unique nature that each individual brings to community;
- Ways of relating and acting within community with an understanding of the principles of reciprocity and responsibility;
- Research participants must feel safe and be safe, including respecting issues of confidentiality;
- A non-intrusive observation, or quietly aware watching;
- A deep listening and hearing with more than the ears;
- A reflective non-judgemental [sic] consideration of what is being seen and heard;
- Having learnt from the listening a purposeful plan to act with action informed by learning, wisdom, and acquired knowledge;
- Responsibility to act with fidelity in relationship to what has been heard, observed, and learnt;
- An awareness and connection between logic of mind and the feelings of the heart;
- Listening and observing the self as well as in relationship to others;
- Acknowledgement that the researcher brings to the research his or her subjective self.

Atkinson's principles are reflected in both the process I used to consent my participants in this study, and in the ways I went about obtaining approval for the use of the data. Weber-Pillwax' (2003) "3 R's of Indigenous research and learning" summed up these principles: respect, reciprocity, and responsibility.

Rains, Archibald and Deyhle (2000) identified the following scholars as the "first generation of Native academic scholars" conducting research with "Indigenous paradigms, Native frameworks, and the power of voice that bring issues and concerns of Native Nations to the forefront" (p. 338), at least in North America: Native American scholars John W. Tippeconnic, Grayson Noley, Mike Charleston, Karen Swisher, Vine Deloria Jr., Elisabeth Cook-Lynn, Donald Fixico, and Bea Medicine, and First Nations scholars Verna J. Kirkness, Marlene Brant Castellano, Olive Dickason, and Carl Urion. Linda Tuhiwai Smith of New Zealand is also foundational for her 1999 work *Decolonizing Methodologies: Research and Indigenous Peoples*, in which she not only made the case for why "research is one of the dirtiest words" (p. 1) to Native peoples, but also provided guidance for where research should go from here. Smith argued that research itself can be a resistance against colonization.

In her chapter of Denzin and Lincoln's (2005a) *Handbook of Qualitative Research,* Smith outlined the purposes of decolonizing research as struggling against existing power structures that seek to silence and marginalize Indigenous peoples, and giving voice to Indigenous experiences in an effort to provide space, liberate, and empower. Indigenous researchers strive "to develop methodologies and approaches to research that privilege indigenous knowledges, voices, experiences, reflections, and analyses of their social, material, and spiritual conditions” (p. 87). Swadener and Mutua (2008) argued that there is no unifying set of methods in decolonizing research, nor even a common definition for it, but the thread that links this body of work lies in the “motives, concerns, and knowledge brought to the research process” (p. 33), being that decolonizing, or anticolonial, researchers seek to privilege the voices that are silenced by “normative research paradigms”. The purposes of the work include “social justice, sovereignty, self-determination, and emancipatory goals” (p. 41).

Swadener and Mutua also spoke of a performative element to decolonizing research, i.e. an activist bent. As Brayboy and Deyhle (2000) pointed out, all research is political; Lomawaima and McCarty (2002) asserted, “The political context of educational research can make the difference between a project that serves Native community and strengthens sovereignty or actively undermines both” (p. 5). Smith (1999) confirmed that Indigenous research is politically invested, and deliberately *not* neutral, and Kenny (2000) spoke of this research as an agent of change: “The last stage of the ritual practice is transformation and renewal. If the research findings are used wisely, positive change will come to the participants. Those ‘innovative spaces’ will be explored. Change will occur and renewal will come” (Kenny, 2000, p. 147).

Kenny’s words evoke an image of research as ceremonial, a theme that Wilson (2008) explored in depth in his book *Research is Ceremony: Indigenous Research Methods*. “The purpose of any ceremony is to build stronger relationships or bridge the distance between aspects of our cosmos and ourselves. The research that we do as Indigenous people is a ceremony that allows us a raised level of consciousness and insight into our world" (Wilson, 2008, p. 11). The metaphors of bridging distance, closing space, and connecting with the people and things that surround us all parallel the third space metaphor; there was a correspondence between the purposes of this study and the purposes of Indigenous research in general.

Methods that may be used in Indigenous research include the conversational method for data collection, in which participants and researchers engage in storytelling and dialogues (Kovach, 2009; Thomas, 2005; Bishop, 1999; Bessarab, 2008; Kahakalua, 2004, Brayboy & Deyhle, 2000); participatory research in which participants collaborate with researchers to develop and implement qualitative studies and to analyze and share the results (Fisher & Ball, 2003; Israel, Schulz, Parker & Becker, 1998; Burhansstipanov, Christopher & Schumacher, 2005), and storytelling for both data collection and analysis (Cajete, 2008; Dunbar, 2008; Kovach, 2009; Wilson, 2008). Each of these options, among others, embodies the values of Indigenous research, which will be described in more detail in the next section.

Values of Indigenous Methodologies

The central role of relationships for developing knowledge is one of the key values of Indigenous methodologies (Steinhauer, 2002; Smith, 2005; Thayer-Bacon, 1997; Wilson, 2008). As Smith (2005) reported, "For indigenous and other marginalized communities, research ethics is at a very basic level about establishing, maintaining, and nurturing reciprocal and respectful relationships" (p. 97). Indigenous researchers attend to the relationships between and among themselves, their participants, the land, their cultural traditions, and the research. As Wilson (2008) described, "Every individual thing that you see around you is really just a huge knot – a point where thousands and millions of relationships come together. These relationships come to you from the past, from the present and from your future. This is what surrounds us, and what forms us, our world, our cosmos and our reality. We could not *be* without *being in relationship* with everything that surrounds us and is within us" (p. 76).

Because of the importance of developing and maintaining respectful relationships, the researcher's intentions for the research – its implications for participants while it is in progress, as well as its implications for whole groups in the future – must be continuously evaluated. Aluli-Meyer (2008) referred to this as a *metaconsciousness*. "Understanding causation in intention and language helps us critically self-reflect" (p. 222). Weber-Pillwax (2003) called the process of self-evaluation of intention "checking your heart". "The researcher insures that there are no negative or selfish motives for doing the research, because that could bring suffering upon everyone in the community. A 'good heart' guarantees a good motive, and good motives benefit everyone involved" (p. 49-50). Researchers also need to be aware of differentials in power between themselves (and their institutions) and their participants (and their communities), and strive to share power amongst the different groups (Bishop & Glynn, 1992; Smith, 2005, Kenny, 2000; Kovach, 2009; Wilson, 2008).

Responsibility for one's actions is another key value of Indigenous methodologies (Denzin & Lincoln, 2008). The researcher is responsible to the participants and their communities, and must be mindful of the history of research misconduct among Indigenous peoples. Kovach (2009) reminded researchers that we must situate this misconduct "as a purely historical phenomenon" (p. 142); in other words, such misconduct can and does still take place. Good intentions are not sufficient, nor is mainstream institutional human subjects approval; the researcher's actions should be guided by the tribal community itself, hence the importance of participatory methods.

In addition, Indigenous methodologies are used to emphasize the strengths of Indigenous communities, rather than the deficits traditionally depicted in mainstream research (Smith, 1999). "The statistics tell a fragmented and distorted picture, which we have to contest. We are not their projected statistics of deficits and dependencies. We are strong resilient creative determined people who are destined to survive" (Battiste, 2008a, p. 6). Wilson (2008) identified a focus on the positive as an element of the axiology of Indigenous methodologies, staying "It's where we choose to focus our energy…We all recognize the terrible stuff that has happened in the past and is going on today in our communities, but there is a common or collective saying of, 'So where do we go from here in order to get over this negative stuff?' What I've learned from Elders while I've been doing this thinking is that focusing on the positive in Indigenous research focuses on harmony…[and] allows for growth and positive change to take place" (Wilson, 2008, p. 109).

A potential point of contention between Western-oriented and Indigenous methodologies is the role of subjectivity (Kovach, 2009). "Tribal epistemologies are a way of knowing that does not debate the subjectivity factor in knowledge production – subjectivity is a given" (p. 111). Brayboy and Deyhle (2000) took issue with Hammersley and Atkinson's (1996) notion of "over rapport" (p. 110), in which the researcher's lack of distance between his or herself and the research community, as a result of over-identifying with community members, results in analyses with "partial perspectives" (p. 111). Brayboy and Deyhle's response was that in their experiences, "it is this *lack* of distance that has enhanced our own research" (p. 165). To Hammersley and Atkinson's position that an autobiography is not ethnography, Brayboy and Deyhle argued that research can be both. To act as if the self is not involved in research, as if we are each merely cameras that record but do not interpret, is an artifice.

Access to the results for the communities involved in the research is another critical component of Indigenous methodologies, which follows from the relational responsibility. This runs counter to the mainstream model, in which the university is in a position of privilege and, most often, claims the territory of the findings on behalf of scholarly publications such as texts and journals, which are inaccessible to the people being studied" (Kenny, 2000, p. 140). Kovach (2009) argued that sharing knowledge is the most obvious means for Indigenous researchers to give back to the communities involved. "Dissemination of the research is a central issue, and it is important to ensure that the research is available to the community in a manner than is accessible and useful. This means ensuring that the research is grounded in community needs, as opposed to the needs of the academy" (Kovach, 2009, p. 149). Researchers must make sure that the research can be understood by the community, that it makes sense to them, and that it serves a need.

Indigenous Methodologies for This Study

Indigenous methodologies emphasize being true to the relationships that support and are built by research, holism, interconnectedness, subjectivity and reflectiveness. Perhaps the most important feature of Indigenous research is responsibility, trying to conduct one's study in a good way and to affect positive change, while maintaining positive, respectful relationships with the participants. Kenny (2000) and Kovach (2009) both talked about non-Indigenous researchers using Indigenous methodologies because of a match between the values of the methodology and the researchers' sensibilities, namely a desire to learn about the world that does not do harm to it or to other people. Although I am not Indigenous, this study reflects Indigenous methodologies because this approach suits the tribal college setting, the care for issues of power, the intention to affect change, the focus on positive qualities, and the deeply contextual, relational, and story-based nature of the collected data.

Obtaining approvals

In his conversation with Kovach (2009), research participant Graham Smith, Indigenous scholar and educator, stated, "If you understand schooling and education as 'selection of knowledge' that is taught in institutions, and that dominant cultural groups can determine what knowledge is selected to be taught, then you will understand how schooling and education become sites for colonization and assimilation" (p. 89). Smith talked about there being a limit to how much can be achieved within the academy because the academy is fundamentally outside Indigenous control. However, this is not the case at tribal colleges, who control their own curricula, priorities, and research.

Although obtaining human subjects approval was indeed important for conducting ethical research, simply going through the university's Institutional Review Board was insufficient. Smith (1999) discussed how the Western value of individuality drives research practices, such as individual consent and individual sharing of information; the rights of the community are not recognized. As Battiste (2008b) pointed out, "vetting research on Indigenous knowledge or among Indigenous peoples through a university ethics committee that does not consider protection issues for the collective may contribute to the appropriation and continuing pillage of Indigenous culture, heritage, and knowledge" (p. 501). Lincoln and Denzin (2008) stated, "One response to this perceived inadequacy [of protection by existing human subjects policies] has been the formulation of a number of local, tribal-entered, or culture-centered sets of ethical principles…Local indigenous protocols grow both more plentiful and more sophisticated by the hour" (p. 569).

The institutional review board (IRB) from the university and the Research Committee at TOCC provided oversight of this research, and both approved the consenting documents use to obtain permission to use student data (see Appendix A, Institutional Review Boards Materials). A proposal for the research that had been approved by my dissertation committee was then submitted to the TOCC Board of Trustees for their initial approval; once this approval was secured, I drafted research applications for the IRB at the University of Arizona, which oversaw the consenting procedures and the protection of participants' rights and confidentiality, and for the TOCC Research Committee, which oversaw the protection of cultural information and ensured that the data and consent forms would belong to the Tohono O'odham Nation and be housed at their Department of Education when the project was complete. For the University of Arizona IRB, this meant that some procedures would be different from business as usual, including this handing over of the raw data and consent forms to the

Tohono O'odham Nation Education Department rather than my department at the university, and allowing for the data and drafts resulting from the research to be reviewed by the college community, and beyond, before publication. These safeties allowed for protecting private cultural information from public dissemination, even though it was unlikely that they would be present in my data. More importantly, however, it allowed for the messages sent out to the broader world about the Tohono O'odham community to be on the *community's* terms, not just my own. Thus, shifting the traditional focus away from the "find problem, find solution" paradigm was key for creating a research methodology that respected the O'odham culture and TOCC community.

Letiecq and Bailey (2004) referred to the approach used for this study as a "community-up" approach (as opposed to "university-down"), which they described as meaning that "the major thrust and focus of the project would be developed by the community rather than being offered by the university partners" (p. 346). This project was "community-up" because it was tailored to address the college's specific mission to integrate the curriculum and the culture. In addition, the curriculum developed for this course originated from within the context of the college culture rather than being adapted from outside sources.

Students were introduced to the research at the start of the semester and informed that their participation in the class did not necessitate their participation in the research, that their grades were not dependent on their participation in the research nor would participation in the research influence my evaluation of their performance in the class, that they could withdraw from the research at any time without penalty, and that their data would not be used without their consent. Each student was then given a handout, on which they could indicate that they were or were not interested in taking part in the research, so that I could consent them privately at a later time. I did this so that each student's choice, to participate or not, would be confidential.

Students were asked again at the end of the semester if they were willing to allow their voices to be included as data. Notably, neither had marked yes or no at the beginning of the class, but at the end both marked yes. This perhaps was the more ethical approach, because the students knew they had this option when we began the class, and they could assess their comfort with including their words as data after already speaking them.

Per my research protocol and consent forms in the traditional university IRB style, I gave each student and other participant in the research a pseudonym. If I were to do this research again, I would leave this decision more open-ended and proceed according to each participant's wishes, a more culturally-appropriate option. Researchers Kovach and Wilson both discussed this issue in their work. "It is about standing behind one's words and recognizing collective protocol, that one is accountable for one's words" (Kovach, 2009, p. 148). Wilson (2008) stated that "relational accountability requires me to name the co-researchers who worked with me on this project and who wished to be named" (p. 10). Several of my participants mentioned that they preferred to be named, and there are several who I wish I could name in order to honor their contributions. I have stuck with the decision to use pseudonyms as my consent forms pledged, but had I known this beforehand, I would have proceeded less dogmatically.

Developing the course

Prior to the Spring 2008 semester when the course was taught, I spent nearly two years on the approvals process and the development of the course curriculum, seeking input from myriad sources to help inform the direction the course would take. In the following sections, I describe the guiding influences on the course development, and how they helped to shape the resulting course curriculum. It is my hope that readers can forgive the categories used to group very disparate individuals and communities; these categories were constructed after the fact. In reality, I sought input from all corners throughout the development process, with no delineation among the different sources. The categories are used here solely to break the narrative into shorter sections, and I begin with scholars and literature because that was where I first turned when I began my journey. Following the descriptions of the different sources of input, I describe how these insights were used to influence the course goals, course philosophy, and my teaching style.

Scholars and Literature

Three simple but profound ideas helped to shape my primordial thoughts when I first started to plan out the course. Long before I began preparing to teach, when I was still in the midst of preparing my dissertation proposal, I encountered an idea in a book I was reading, *Power and Place* (Deloria & Wildcat, 2001), which struck a chord with me. Deloria and Wildcat suggested that the abstract of physics connects with the deeper philosophies underlying Native ideologies. The authors discussed how Native Americans are typically systems thinkers who view the natural world holistically, seeing relationships among the components, including relationships to emotions, spirit, and meaning. This started me thinking about ways to characterize physics that would resonate with my students. In a journal entry two years before teaching the course, I wrote the following:

> Reading through *Power and Place* this afternoon, and seeing once again how quantum physics, chaos theory, and nonlinear models resonate with Native metaphysicians, it occurred to me that my physics course ought to begin with these ideas. Or be grounded in them. In mainstream physics, I think of these concepts as being "high level", i.e. way above my expertise in the subject; physics 101 tends to be the really concrete, most reductionist material, and as you progress in physics you separate more and more from the "intuitive" (to Western-raised people) and get more and more into the abstract. *Power and Place* suggested that the abstract of physics – relativity, quantum theory, chaos, and all of that – connects with the deeper philosophical underpinnings of Native ideologies…I think it would be important to talk about the typical structure of physics studies, and how this deviates from it and why, and help the students to understand that I'll be a lot more a guide than a font of knowledge. We'll see.

This entry shows how, long before teaching the class, I had already been thinking about how to present it with a critical perspective of science, highlighting typically "Western" and typically "Native" perspectives; it also hints at a foundling desire to share control of the course with the students, being more of a "guide" than a "font of knowledge." This led to a goal of guiding students to further develop their understandings, rather than processing knowledge for them to merely digest.

The next influence shaped the way I thought about teaching. During his keynote address at the University of Arizona's LRC Graduate Student Colloquy, Dr. Brayboy (2008) stated that education should be for a purpose; namely, for the purpose of equipping students for the world in which they will – or in the case of adult students, do – live. New knowledge should be imbedded within a meaningful context that justifies the effort required by students to learn it.

Another important influence on my thinking, this one with regard to preparing science curricula, was the guidelines for culturally-relevant pedagogy set forth by Ladson-Billings (1995a), being that students must experience academic success, develop and/or maintain cultural competence, and develop a critical consciousness through which they challenge the status quo of the current social order. These guidelines, along with the two ideas from Deloria and Wildcat and from Dr. Brayboy, provided a loose conceptual framework upon which I hung the lessons I learned from my interactions with the educators and students described below.

Indigenous and Non-Indigenous Educators

Early in my process, I spoke with an American Indian scientist and science educator at another university, who talked about knowing and being strong in who you are, as well as learning from the mainstream culture, taking the best of both. He advised instructors like me to get to know their students and their cultures, experiencing life from their eyes; from these experiences, instructors can mold their teaching to fit their students, rather than trying to get their students to fit them. However, he also felt that Native students should learn the same things that any other student learns for the sake of equity, a position that at the time I thought was inconsistent with the notion of adapting teaching to the students, but later came to realize was not. I believe he was not saying that all students should have equivalent, one-size-fits-all learning experiences, but that students should all have the opportunity to learn the same knowledge and skills in the way that works best for them.

A first step toward molding my teaching to suit students' learning styles was to learn from traditional O'odham educators. The design of this physics class was informed by the example of one educator in particular, an O'odham elder and foundational member of the TOCC community who taught classes on O'odham language and culture at the college. Instructors at TOCC are required to take at least one of these courses in order to learn about O'odham culture, and I was lucky enough to be in this educator's class. He allowed me to take notes on what I experienced in his class, in which I reflected that the pedagogy he had adopted was a blend of story-centered and student-centered. A selection of my notes from the class follows, with a pseudonym for the instructor:

Observing Mr. Gerard's teaching style gave me some insight into the teaching and learning styles with which my students would be comfortable, although it would not necessarily but appropriate for me to use them all of the time. Mr. Gerard's teaching is definitely teacher-centered, meaning that it is he that leads the class the majority of the time while the students listen and take notes, but it is not lecture-focused as most teacher-centered classrooms are. Rather, it is storytelling-oriented, which is quite different. The content of the course is built around certain content goals that Mr. Gerard has presented in his syllabus, and what he seems to do is tell stories that weave these content goals into a broader framework, providing a well-contextualized body of knowledge that paints a very three-dimensional picture of what it means to be O’odham. The stories include those drawn from his own life and the recollections of others he has known, traditional stories passed down orally through the generations, and history as presented by our text (*Sharing the Desert* by Erickson, 1994). It is actually a very [exceptional] teaching style, and would not be possible without a very broad and deep knowledge of the content area. It would certainly be difficult for me to recreate in a science classroom, but definitely worth considering as an option for introducing and/or recapping certain concepts. I can see how it does fit into a constructivist teaching philosophy, although it would be classified as a “passive” teaching method in a classical sense. What it does is provide the context for students to connect to on a personal level, seeing the content through the eyes of people who have lived it as opposed to being presented with loosely-associated facts.

Another method Mr. Gerard uses is the student-centered review of the class’ topics, which is very much a social constructivist approach. He asks the students to discuss what they’ve learned in small groups, then report back to the whole group. Although the directive is to talk about what’s been learned…what students tend to do is to extend the discussion by adding their own experiences, reinterpreting the material and personalizing it even further. This is also an opportunity to speak with our classmates about questions we have, to bounce ideas off each other, and to pose questions to the broader group to draw out yet other ways we can connect with the content.

Mr. Gerard’s teaching helped me by demonstrating a pattern of communication that could be used in my own classroom. His class also highlighted the value of hybridity, where lived experiences of the instructor and students were resources to be drawn into a dialogical third space to enhance and deepen the learning of all members of the class. Another important lesson I learned from Mr. Gerard's class was how to incorporate elements of the *Himdag*. As I wrote in my reflection on the course:

> The values we've talked about in class are being industrious, being an early riser, kinship, respect, health, and watch and learn. I can see each of these being included in a physics class. Respect is important for the classroom environment, and can be talked about as the way we treat each other when either the teacher or the students are speaking or presenting. Even being an early riser, not as obviously relevant, is something to point out to those students inclined to procrastinate on getting their work done (myself included). Being industrious is another that fits well with a classroom philosophy; a good lesson for group work but also relevant when talking about the applications of science to the community. Science should always be considered within a societal context; if it's not doing something useful, not contributing, it needs to be reevaluated.
>
> Kinship is actually a really interesting principle when applied to physics. Of course, in terms of the *Himdag*, it refers to the relationships between people [Note: As well as relationships in the natural world], and being able to see yourself as part of a network of individuals, all related. The thing to point out there is that the universe works in the same way, and that physics can be seen as the study of the universe's kinship. All things are related, all things interact, and physics examines those relationships and interactions. This is an idea worth exploring with students.
>
> Health is another that is not as obviously applicable, but if looked at a certain way has a lot in common with physics. Health is when things are in balance; if a system strays

from this balance, it can become unhealthy. Balance is an important principle in physics too; you can look at it as the balance of forces in a number of different scenarios, many of which are included in the physics curriculum. This is another idea worth exploring.

Another source of cultural information pertinent to teaching was the Himdag Committee at TOCC. The Himdag Committee is a group of O'odham faculty, students, staff and community members who help to ensure that the Tohono O'odham Himdag, which encapsulates the entirety of the O'odham way of being in the world, is present at the college. Their role is to help incorporate the Himdag into the college's programs, policies, and curricula. I met with this committee when I was in the process of developing my course to seek their input on ways to connect my curriculum with the O'odham culture, to learn about traditional teaching methods, and to determine what the committee was hoping students would learn from this class. The Committee also had advice for teaching practices, telling me that O'odham education was more hands-on and observational versus lecture-oriented, which was positive for me because this was my preferred teaching style. What I did not expect was when I asked what the perfect science class at TOCC would be like, and was told that "everything would be in O'odham," meaning that including the language would be a far more important part of cultural relevance than I had expected. Obviously I with my one semester of O'odham language was not in a position to teach the whole course in fluent O'odham, but I was able to work with the Himdag Committee to find translations of some physical terms, some of which were brought into the classroom in the course of discussion. One member of the committee mentioned that they had once seen an instructor relate the linguistic analysis of words to kinship; this led to a discussion about the concept of *i:mig* (kinship) and how it could be applied to how physics sees the universe as connected through forces and energy.

The Himdag Committee also talked to me about things that were not appropriate to do – namely mimicking animal sounds and whistling at night – which would have been quite pertinent had I taught the physical science general elective that included sound, but did not come into play in the strict syllabus of the introductory physics class. Nevertheless, this advice was helpful because it allowed me not to be overly cautious about doing the wrong thing because I knew about some things to avoid.

I went before the Curriculum Committee at the college in order to propose the physics curriculum to them, a necessary step before a new class is offered (courses must also garner approval from other committees, such as the Himdag Committee). The Curriculum Committee criticized the traditional approach to physics as having an aggressive attitude toward the Universe. I was asked to rephrase the course description, and thus restructure my own conceptualization of physics, with this in mind. In a journal entry shortly before the start of the semester, I wrote the following:

I don't want the students to see physics as the discovery and stating of "laws", as it is so often described. This was clearly denounced in that meeting I had with the curriculum committee, as having an almost war-like outlook on the universe, as humans attempting to *apply* laws and rules to the universe instead of recognizing that we are governed by those same rules. And using words like "govern" and "law" are likewise reflective of that imposing perspective. I didn't really understand this when I first heard it, and I resisted it at first, but after reading a little more of *Power and Place* I can see how it fits with a broader sentiment: Western society tries to break the universe down and make it fit into simplifications the society has derived for it; Native societies avoid over-simplifying by looking at the bigger picture. This description is not really doing justice to the idea, and I'll need to capture it more thoroughly when I write this research up, but for now my point is that if I want my students to have an understanding of physics – its purview and content, not physics as a field – I need to be able to convey the idea that physics explores the world and tries to understand its underlying, fundamental processes. Understand, not dictate. It's a subtle distinction, at least to me, but if I understand correctly (doubtful), it might make a big difference to a Native student.

This goal reflects a critical perspective of science, and is in line with both the curriculum committee's recommendations and the goal of aligning the course with students' perspectives of the world. Through this input, I reconceptualized physics as discovering processes rather than defining laws.

Science faculty members at the college contributed to my preparations for the class by talking to me about their experiences teaching at the college, and about what I might expect in terms of the academic atmosphere – such as students' expectations of the faculty, the faculty's expectations of the students, students' home lives, and typical pre-college academic preparation. The faculty members modeled for me different ways of weaving the culture and content together, and different approaches to being responsive to students. I spoke with the other members of the science faculty in a collegial, rather than research-oriented, manner, seeking out guidance from their experience. They helped me in making logistical decisions about the class through their knowledge of students' tendencies with regard to homework, writing, reading, math skills, and technology. They were enormously helpful throughout the development and implementation of the course, willing to answer any questions I had and to help address any dilemmas I was facing.

One faculty member in particular, whom I call Jiles, helped guide the course through his input into cultural connections with the content. He acted as a cultural advisor to the course, and I met with him throughout the semester to seek his thoughts about directions I could take to draw in examples from O'odham culture that were relevant to the concepts we were learning about, as well as ways that the O'odham people developed and used scientific information. In addition, he was a presence in the classroom, leading a multi-week lab activity in which the students constructed an ancient North American weapon, the atlatl, from local materials, then tested it and learned about the physics that applied to it. Toward the end of the semester, he related a traditional O'odham story relating to seasons that served as the foundation for our unit on thermodynamics.

Faculty members and colleagues from my home institution also contributed their insights to the course and the research. A science education colleague from my home university, whom I call Sally, was a guest to our classroom; she was there to evaluate my teaching, but also interacted with us in the classroom through my prodding because she too was knowledgeable about physics and about teaching at the community college level. A physics faculty member from the university also contributed to the course, from its development through the analysis of the data. She helped me think about ways to integrate culture and the traditional introductory physics content.

Student Development Team

The importance of incorporating student input cannot be underestimated in the tribal college environment, where approximately two-thirds of the faculty nationwide is non-Native (Voorhees, 2003). We non-Native tribal college instructors generally are not as intimately familiar with the language and traditions of the cultures in which the colleges are imbedded. Even Native instructors and students may not necessarily be grounded in the traditional tribal culture and epistemology. However, the goal of cultural relevance is as much to validate students' cultures – in whatever form they take – as to validate the traditional culture. Thus, sharing power and responsibility for the curriculum with students is a pivotal tool for integrating cultural relevance with the content and supporting our students' identities and success.

During the semester prior to the one in which I taught the course, I held a paid internship at TOCC for a small group of students, the Student Development Team, in order to solicit student input into the course design and content. Three students took part in the internship, for which they received a small stipend at the end of the semester. We talked about learning styles and preferences of TOCC students; the interns' insights into what students want to get out of a class, how they prefer it to be structured, and what they want to see in a syllabus; possible connections between students' interests and physics to show how physics can relate to them; and what the O'odham as a people know about science, as interpreted through the students' conversations with elders like their grandparents. One of the students who took part in the internship (Drennan) later went on to take the course because of his particular interest in science.

Goals for the Course

While the college had the established goal of offering this course as a lab science elective transferable to any Arizona university, there were yet a number of different directions the curriculum could take based on my goals for student outcomes. I brainstormed potential goals at the beginning of the course development phase; Bryan Brayboy's (2008) message was important for helping me think about what the purpose and the context for learning physics should be. Possible goals that I considered were to familiarize students with the field of physics; to get them to think scientifically; to expose them to the content of physics; to prepare them for future study of physics; to prepare them for future study of science in general; to help them fulfill a college requirement in the least assimilative way possible; and to allow them to pursue an understanding of their own culture's physics understandings. I struggled with what I saw as the incompatibility between my hopes that the course would encourage my students to go on in science, and my perception that a culturally-relevant curriculum may not prepare students for a standard university science course, where professors lecture and give tests and expect students to see things their way.

Reading *Power and Place* (Deloria & Wildcat, 2001) influenced my decision to ground the physical concepts of the class in philosophical ideas that emerge from more abstract physics like quantum theory, chaos theory, and nonlinear models. The fundamental uncertainty of physical properties at the quantum level, for instance, is seen to be indicative of spirit, which cannot be measured but which has a tangible effect on the measurable. This meant that the course could show students where and how even the most abstract of the sciences can connect to their sensibilities in fundamental ways. My own experience as a student in introductory physics was a reminder that even when students do not expect to pursue a career in science, one single class may provide the inspiration. If students were to continue studying science, finding meaning in the content they encountered in more mainstream educational settings would be up to them. I wanted them to understand that the way we approached science in this course may be different from how it is approached in other places, but that using the same skills and understandings they developed in this class would help them to find meaning in other kinds of science too. This idea, of the students developing a foundation upon which to build learning of other sciences, became the overarching goal of the course, layered over which were the content and skill acquisition objectives of standard physics courses that serve to develop students' understanding of the structure of the Universe in which they live. The curriculum was designed to prepare students for future studies, but was grounded in the belief that students will be better equipped to become scientists (amateur or professional) if they are strong in their identities and know how to rectify their culture and their science knowledge by seeking out the fundamental connections between them.

Course Philosophy

The input I received from the American Indian scientist and educator mirrored Ladson-Billing's (1995a) criteria for cultural relevance. His experiences as a student of science and as an educator teaching other Native students reflected the first criterion of having experienced, as well as fostered in others, academic success in learning science. He also communicated to me the importance of recognizing that different cultures have their own way of looking at physics, reflecting the second criterion of respecting culturally-based science. Like him, my students would have a cultural heritage of science, and both they and I should respect that distinctive knowledge rather than condemning it as “wrong” compared to Western science. This educator’s advice challenged the status quo, as the third guideline advocates, by calling for instructors to adapt to their students’ strengths and needs, rather than forcing their students to change to fit them or suffer the consequences of academic failure. The success of these students, and the possibility that they would go on to become professional scientists, likewise would challenge the status quo that tends to exclude this population.

The connection between the science educator’s insights and Ladson-Billing’s criteria led me to create a modified set of guidelines specific for culturally-relevant science learning: the curriculum must (1) allow students to experience success with science learning; (2) recognize that students have a valuable scientific heritage associated with their culture; and (3) support them in challenging the status quo within the fields of science and science education. These modified guidelines for the curriculum served as the philosophy of the course.

Teaching Style

The other science faculty members at TOCC provided examples of cultural and content integration with their teaching, and my Student Development Team, our class cultural advisor, and the Himdag Committee were sources of potential connections between physics and O’odham culture. These same sources, along with the Tohono O’odham history and culture course, gave me insight into TOCC students, information I was able to use to center my teaching on the students, as directed by the advice from my contact at a different university. This advice also turned my attention to the need to make space for student voice and storytelling, as demonstrated by my history and culture instructor, and to include the O'odham language, as suggested by the Himdag Committee. The Curriculum Committee's input caused me to rethink my choice of words even in my own language, bringing forth a reconceptualization of physics that was manifested in my Course Description (included in Class Structure below).

I am not a natural storyteller, and thus I was not sure how to approach the use of storytelling as a means of weaving course concepts into a context rich with personal and historical connections. However, student-directed storytelling was a strategy that I could use in my own classroom, and it happened naturally simply because I was open to it: I gave students the opportunity to voice their stories when they brought them into course dialogues.

The contacts from my university helped me contextualize my pedagogical decisions within academic literature and compare them to mainstream physics instruction. As the one visitor to the classroom from outside the TOCC community, my science education colleague (Sally) provided me with a perspective on the class that no one else could provide, helping me to think about the decisions I had made in constructing the classroom environment and what sources I could look to from the literature base to validate my ideas. Sally proved invaluable for assisting me in connecting my practice to research. Following my data collection, the university physics instructor helped me contrast the TOCC course with its equivalent at the university, which she frequently taught. She brought her experience with university introductory physics students to bear when helping me examine the dialogues of my students, to see how the evidence of their learning was similar to and different from what university intro physics students would learn. This helped me to focus on the learning that was particular to this class.

Cultural Connections

I didn't really understand the message from the Curriculum Committee about the tone of human imposition when I first heard it, and I initially resisted the message. Nevertheless, it encouraged me to further reconceptualize physics, away from thinking about it as discovering the "laws" that "govern" the Universe. Reading more of *Power and Place* (Deloria & Wildcat, 2001), I began to see how the Committee's message fit with a broader sentiment: Western society tries to break the Universe down and impose a simplified structure on it; Native societies avoid over-simplifying by looking at the system holistically and accounting for irregularities. Thus, the input from the Curriculum Committee reinforced the notion of characterizing physics as a means of seeking an understanding of the relationships among components of the Universe.

The message from *Power and Place*, that students should be encouraged to make meaning from the content, colored the questions and topics I asked students to consider as they learned the content, including parallels between physical concepts and the Himdag. Having learned about the Himdag through my O'odham history and culture course and talked about it with the Himdag Committee, I attempted to connect it with my teaching. As described above, the course was influenced by the following values from the Himdag:

- Being industrious, relating to members of the class having to work hard, but also to the outcome of work being for a purpose; I related this value to science knowledge needing to have a purpose and to contribute something to the people.

- Kinship, or i:mig in O'odham, refers to the relationships among people and between people and the natural world, and being able to see oneself as part of a network of connections. The Universe works in the same way; physics can be seen as the study of the Universe's kinship: all things are related, all things interact, and physics examines those relationships and interactions.
- Health is when things are in balance; if a system strays from this balance, it can become unhealthy. Balance is an important principle in physics too, and can be viewed as the balance of forces in a number of different scenarios, many of which are included in the introductory physics curriculum.

Summary of Input on the Course

These varied sources of input all contributed to the development of the course based on (a) Ladson-Billings' modified guidelines for culturally-relevant pedagogy; (b) Brayboy's (2008) assertion that learning should be for a purpose; and (c) Deloria and Wildcat's (2001) suggestion that the abstract physics concepts are more in line with Indigenous thought, but grounded in the lived experiences of the students, instructors, staff, and myself. The largest influence on the direction of the curriculum, however, was of course the students, both those who helped develop the concept of the class and those who took it; describing the students' learning of physics as evidenced by their classroom dialogues is the focus of the next chapter, though the students and course structure are briefly described below.

Description of the course

Participants

The class that served as the research site for this study was very small – five students at the outset of the semester, dwindling to two who completed the class and participated in the study. This small number of enrollees, despite the fact that this class was the only physics course offered that semester, was likely influenced by a number of factors, including hesitance to engage with the seemingly-advanced content matter of physics, the peculiar timing of the course (all day, once a week on Fridays), and the small number of students at the college overall (approximately 250 the semester the course was taught). The two students who participated in the research were both male, and of similar ages to myself (late 20s).

One student, whom I call Drennan, was a local who was raised on the Nation. He was in college for the first time, choosing to attend so he could show his nieces and nephews that they can do whatever they want. He also wanted to show that he could start and finish something, to have that accomplishment. His goal for his college career was to ultimately obtain a bachelor's degree in business so that he could start his own family business and help himself and his family.

The other student, whom I call Dylin, had recently come back to the Nation after being raised in a more urban lifestyle. Dylin had been at the college for several years already, to fulfill the requirements in order to "have a piece of paper that says I have a degree…it's just something that society says you have to have to get a better paying job". He took our class because it fit with his schedule, and he did not have much prior knowledge of science, but said he enjoyed doing experiments rather than having a reading and lecture-heavy class. Both students were taking the course to fulfill a science requirement, and pursuing a degree in order to be eligible for better employment opportunities. Drennan also expressed a personal interest in science, and Dylin in science fiction.

The students had very different familiarities with the O'odham culture because of where they were each raised. Drennan spoke the language and was familiar with cultural traditions; Dylin did not speak the language but still identified strongly as a tribal member. In identifying what was "cultural" for the students, I followed Cajete's (1999b) lead. Cajete wrote: "The reality of a culture experienced by a student may be a *collage* of values and perceptions that does not resemble very closely the statements in the literature [about the culture]. The student's reality does not negate traditional realities of the culture but exists beside or intertwined with these realities" (Cajete, 1999b, p. 152, emphasis in original). Smith (2005) related a similar perspective: "[I]ndigenous communities hold an alternative way of knowing about themselves and the environment that…may be different from what was known several hundred years ago by a community, but it is still a way of knowing that provides access to a different epistemology, an alternative vision of society, and alternative ethics for human conduct. It is not, therefore, a question of whether the knowledge is 'pure' and authentic but whether it has been the means through which people have made sense of their lives and circumstances, that has sustained them and their cultural practices over time, that forms the basis for their understanding of human conduct, that enriches their creative spirit and fuels their determination to be free" (p. 101). In summary, culture lives and breathes through people in a dynamic world over time, and cannot be reduced to essentialist notions about "counts" as cultural according to some external authority.

This same notion can be applied to individuals; though Indigenous people have varying levels of connections to their tribal community, and thus their knowledge of and identification with the tribe may not be "complete" (and whose is?), there is a recognition that the cultural identity is different from everyone else's, that there is an influence that shapes the way of interpreting and understanding the world that is distinctive. It isn't a matter of whether each's perspective is *the* pure and authentic perspective of the people, but that each individual's perspective is a piece of it. Likewise, the students' perceptions of their own culture are unique to them and overlap with their personal identities. These personal-cultural identities were what the course was trying to tap into, rather than imposing my own notion of O'odham culture on the students. Each student's individual notion of "culture" is potentially distinct from "O'odham culture", either stereotypically or otherwise defined, yet was not less valid.

Negotiating the Syllabus

The class taught at TOCC in Spring 2008 was identified as Physics 121, an integrated lab and lecture course of five credit hours which paralleled the course offered at Pima Community College, a well-established system of community colleges in the Tucson area. Prior to TOCC's full accreditation in 2005, its classes were accredited through Pima Community College via an intergovernmental agreement (Tohono O'odham Community College, n.d.), thus many of TOCC's courses are modeled after Pima syllabi in order to help ensure that the courses will be transferable to other institutions, just as Pima courses are.

It was decided by the college that the course would be offered all day on Fridays so that dual-enrolled high school students could take it; high schools on the Tohono O'odham Nation do not hold classes on Friday. Coordinating with the curriculum specialist at the college, I arranged for the class to meet from 9-2:30, with 30 minutes for lunch. Sixteen hours were trimmed from the regular class day to be set aside for field trips.

A posting with selections from Mano Singham (2007) on Tomorrow's Professor, a listserv devoted to discussing faculty careers edited by Rick Reis of Stanford University, inspired the idea to incorporate the students' input on the course rather than dictating its structure myself. The posting encouraged instructors to invite students to co-create the syllabus, an idea that appealed to me as an opportunity to share power in the classroom by negotiating the course structure, if not specifically its content. Starting from the course outline from Pima and the required textbook, I planned to share the course goals (e.g. concepts to understand, skills to use, some possible assessments) that would need to be integrated into the course structure we came up with collectively, some performance objectives I wanted to see them meet, and a list of the topics we would be covering along with some general information about each. I would provide an overview of what the course would be about, including the nature of science and physics from different world perspectives, the list of topics and performance objectives (e.g. being able to apply concepts to novel situations, describe a concept to another, utilize good lab skills, ask questions and pursue answers, etc.). Finally, I would give the students a list of areas we would negotiate together. Some elements were not negotiable, such as the number of credit hours and the course objectives. Some were semi-negotiable, like the course goals and topics. Still others were completely negotiable: teaching styles, assessments, class start and end times (so long as the requisite number of hours were met), homework system, due dates, grading scheme, class rules, etc.

Following this line of thinking, at the beginning of the semester I brought to class a course description that I had composed, which was based on the Pima course description and the input gathered from all the individuals who helped me during the development of the course.

> Introduction to general physics. Includes mechanics (motion), heat, energy, and gravity. Discusses the systems that organize the universe and the ways in which all things in the universe are connected. Useful for programs requiring a one-year, non-calculus based physics course.
>
> This course will provide students with a culturally-relevant experience with introductory physical science, which will help them develop a meaningful connection with the field of science and aid them in their future studies. The course will also emphasize the development of essential skills, such as critical thinking, math, communication and the use of technology.

I also brought in a tentative list of the goals of the course, a combination of the problem-solving objective from the Pima course syllabus (#3), the college's emphases on writing, math skills, and technology (#3, 5 and 6), and my own goals for students' understanding of the nature and practice of science (#1, 2, and 4).

> By the end of the semester students will be able to:

1. Discuss the nature of science.
2. Identify the O'odham perspective(s) of science and compare and contrast different cultures' perspectives on and uses of science.
3. Use critical thinking and an understanding of physical concepts to solve problems.
4. Pose questions about the physical world and devise experiments to investigate them.
5. Explain and write about physical concepts covered in the course.
6. Utilize technology(ies) to enhance and communicate their learning.

In lieu of a formal syllabus, I brought the initial course description and goals, along with a list of topics from the Pima Physics 121 syllabus, to the first class (and the next class, since only one student came to the first session) to talk about with the students. We then constructed the syllabus together, adding students' goals for the course, discussing students' preferences for teaching and learning styles, and putting together a plan for student evaluation (see Appendix B, Course Materials, for the full syllabus).

Two goals were added based on students' input.

By the end of the semester students will be able to:

7. Gain a better understanding of the world.
8. Use science-related skills independently.

The grading scheme developed with students focused heavily on class participation, reflecting the students' sense that their strengths in demonstrating their learning occurred verbally during class discussions. The minimal emphasis on homework reflected students' belief that they would not focus meaningfully on their work on their own; instead, they posited that the evidence of their preparation for the course would be apparent during class.

Homework	5-10%
Class Participation	50%
Activity Reports	15%
Exams	15%
TBA	5-10%

Overview of the Course

During the 13th class session at the end of the semester, an external observer of the course, my colleague Sally, visited the class. Sally's objective was to get a sense of the pedagogy and climate of the course, in keeping with her professional role at the university. In her report on her visit, she wrote,

> The atmosphere was casual as Jessie taught using one-on-one discussion, lecture, and guided inquiry. The curriculum emphasized personally relevant links between everyday life and Western conceptions of science. This was accomplished using everyday examples to describe scientific phenomena, student-provided examples of material (e.g., connecting concepts to movies), and hands-on, concrete experiences with guided inquiry (e.g., building pizza box ovens to cook smores).
>
> Even with the individual class size, there was a sense of community, respect, and autonomy that was palpable between Jessie and the student. Even though the major class elements were planned and primarily decided upon by Jessie (with some exceptions –

choices of the order of class activities were offered to the student, for example), the relationship was more of equal colleagues sharing experiences, rather than a traditional one-way transmission of knowledge style of teaching that characterizes Western education and science. This was accomplished through the use of everyday language, rather than excessive jargon; a relaxed atmosphere; tone of voice, pace, choice of words, an unassuming air, and seemingly non-evaluative feedback, that promoted this sense of collegiality instead of condescension. Jessie also allowed the student to take his time with the various class activities, supporting that sense of autonomy.

The class was always a co-constructed dialogue between the students and me; although I did spend some time at the board drawing and writing notes, we forewent lectures in favor of dynamic discussions. The course interactional pattern was similar to what Indigenous researchers refer to as a conversational method, which “shows respect for the participant’s story and allows research participants greater control over what they wish to share with respect to the research question” (Kovach, 2009, p. 124), or with respect to the course content, as was the case in my classroom. This also allowed what Bishop (2008) defined as a dimension of reciprocal learning, “which means that the teacher does not have to be the fountain of all knowledge but rather should be able to create contexts for learning where the students can enter the learning conversation” (p. 443). This dialogical pattern gave me access to the students’ thinking, gave the students opportunities to ask questions and pose scenarios, and provided the raw material for developing understanding by building upon the input of the members of the class.

Later, Sally and I discussed what it was that made this class light up with connections. It was due in large part to the environment of the institution where the class was taught, where it is part of the very mission of the college to support students' identities. As instructors at TOCC, we were encouraged to make connections across disciplines, and given a great deal of autonomy in designing and teaching courses. This translated to greater autonomy and ability to make connections on the part of the students, which was essential for building meaningful understandings.

"[Culturally relevant education] constitutes the classroom as a place where young peoples' sense-making processes are incorporated and enhanced, where the existing knowledges of young people are seen as 'acceptable' and 'official,' in such a way that their stories provide the learning base from whence they can branch out into new fields of knowledge through structured interactions with significant others. In this process, the teacher interacts with students in such a way (storying and restorying) that new knowledge is co-created. Such a classroom will generate totally different interaction patterns and educational outcomes from a classroom where knowledge is seen as something that the teacher makes sense of and then passes on to students" (Bishop, 2008, p. 456).

Reading this, years after the class was over, was like reading my own history. All that is being said here directly reflects the things I found to have been successful in my class, and like Bishop says the interaction patterns, epistemology, and outcomes were different from traditional patterns. This is serendipity, a converging of like-minded educators; what happened in our classroom completely supports and is supported by the literature base.

The class time was used primarily to talk about content and try out using it, often in the form of solving problems or trying experiments. The class sessions were designed to each focus on a particular unit of the physics curriculum, though in practice the lines between units were often less distinct. Each class was of course a little different from any other, but in general our time was spent on a combination of problem-solving, activities, and discussion. Lecturing was not dominant in the classroom, both because I preferred other methods of conveying content, and because with such a small class it was not appropriate lecturing to one single student, as was often the case. Instead, student questions drove more egalitarian conversations that wove around the unit concept, where it was my role to bring in the content and tie it to students' experiences, curiosity, interests, and backgrounds. The students, for their part, maintained a high level of engagement in the classroom activities and stayed on task the majority of the time.

A typical class day would involve working with some math problems, because the students expressed an interest in becoming more fluent in algebra. Despite the fact that the class had a math prerequisite, this was overlooked during registration and none of the students had met it. Whatever time was not spent working through physics problems was spent on lab activities that pertained to the content of the week's unit. Activities included engineering challenges, such as designing a pendulum to time 20-second intervals; hands-on demonstrations, such as demonstrating air pressure differentials by sucking an egg into a bottle; experiments, such as determining the distances traveled by air-powered rockets or handmade atlatls; as well as paper-and-pencil activities, such as worksheets promoting conceptual understanding of projectile motion.

Topics: We spent the first half of the semester talking about mechanics: motion, including velocity, acceleration, and Newton's Laws; gravity, including acceleration due to gravity, free fall, and terminal velocity; and projectile motion, with labs with rockets and the atlatl. In the second half of the semester, we worked on energy, impulse and collisions, thermodynamics, and hydraulics.

Attendance: Out of a total of seventeen scheduled class sessions plus one field trip that counted for class time, there were three times when no students were present (17%). Drennan was present for ten sessions (56%) and Dylin for eleven (61%). There were only six class sessions (33%) when both students in the research were present. There were also four class periods (22%) where a student in the research was present with a student not taking part in the research; although I could not collect data from the latter student, the presence of this student necessarily changed the dynamic of the classroom so it is worth noting. It is also worth noting that neither of the students who were not part of the research stayed with the course, despite my best efforts to retain them; both of the students who did not complete were dual enrollment high school students.

Field Trips: Although the course was designed to include 16 hours outside of the classroom in order to fulfill the requirements of the five credit hours, only one of these out-of-class events took place (and it actually took place on campus). I had planned for a trip to the local rodeo in the early part of the semester, possibly a trip to the University of

Arizona campus to visit science labs and/or investigate the physics of carnivals at the Spring Fling event in the spring, and for the students to do a booth at a community night event put on by the students at the tribal college. The latter event was never scheduled, and the other field trips never happened due to attendance.

Graded Assignments: I assigned the students weekly journals on their readings with some guiding questions, which one of the students ultimately did do all at once at the end of the semester, but the other did not. I had intended for these journal entries to be made into a portfolio that represented the students' journey through the semester, but it did not turn out this way. Other graded assignments were problem sets and questions from the text, various worksheets from other resources that I brought in, and participation in activities such as building and testing an atlatl. We had two formal exams: a midterm and a final (see Appendix B, Course Materials). I also assigned the students to do a project of their choosing at the end of the semester, which one of them completed (incidentally, not the one who did the journaling).

By the time of the midterm I had very little upon which to base grades, and we had a discussion about our grading scheme and our honest evaluations of the effort being put into the class. The silver lining was that, perhaps because of the ownership the students took in constructing the course, they took responsibility for their own part in not meeting the co-constructed expectations, and made plans to rectify their respective situations. Both students ended up passing the course at the end of the semester.

Data collection procedures

The data for this paper were derived from transcriptions of audio recordings of fourteen class sessions. Seventeen sessions were planned, but three of these saw no students in attendance. The recordings, made primarily by an mp3 player hung around my neck as I taught, were initially designed only to document my own speech as I modified the curriculum and made pedagogical decisions in real time, as at the start of the research the scope of my study extended only to the development of the curriculum and students' input on it via their classwork and interviews. However, when student voice during class dialogues emerged as a crucial element in the co-construction of the curriculum, my research questions evolved to examine how sharing power with the students contributed to the direction the course took, and ultimately to how students made meaning with the content. Students' permission to use their recorded voices as data was then sought and subsequently granted.

Seven of the recordings were transcribed by a transcription service, one short recording was transcribed by a friend, and the remaining six I transcribed myself. The transcribing service saved me a lot of time, but they certainly did not deliver a finished product: they didn't distinguish between students; they didn't have a background in the content so they missed and misinterpreted a lot of the conversation; they obviously couldn't accurately capture the spoken O'odham; and some of the time what they heard did not at all match with that was really being discussed. As a participant in the conversations, it was a lot easier for me to more accurately interpret the voices, so I read through the transcripts looking for instances of (a) establishing the class environment on my part and (b) meaning making on the part of the students, and compared the recordings to the transcripts making substantial edits to create better representations of the dialogue. This was one of the earliest steps in the analysis of the data.

I also captured my own written reflections on the class in order to provide a record of what was going on in each class session as well as my thoughts, pedagogical decisions, and reactions to students at the time. I wrote about whatever salient issues or moments arose in each class, sometimes logistical and sometimes pedagogical. These reflections were initially intended to help me gauge the "effectiveness" of my efforts (loosely defined), but they also served as a guide to the analysis, drawing attention to particular dialogues that seemed important during the moment, which I could then revisit with a focus on understanding how meaning was being made. My reflections were particularly useful in pinpointing the moment when my research questions changed, as evidenced by the selection that opens up Chapter 1 of this dissertation. Following this class – our 10th class session, one month before the final – I realized that what the students were talking about was having a tremendous impact on their learning and the direction the class was taking. It was lucky for me that, for one, the students' indirectly-captured voices on my recordings were reasonably clear, and that the students granted their permission for me to use their dialogues as data.

Additional data were collected as part of the research project, which were not used to inform the research question per se but which contributed to shaping the research nevertheless. Student work was collected, yet this did not constitute a complete body of data because written work from the students was so rarely submitted, and because some of what little student work I had was lost due to an error in judgment I made. I conducted a post-semester interview with my colleague who provided the external evaluation of the course, which was very helpful for thinking through how the course was structured to include student voice, though of course this interview itself did not contain student voice; an excerpt is included above.

Post-semester interviews were planned with both students who took part in the research, but only one of these, with Drennan, actually took place. I lost contact with Dylin after he missed our post-semester interview, so this part of the data collection was also incomplete. However, Drennan's responses on the post-interview supported the conclusion I had drawn in my reflection on the 10th class. He expressed not only recognition but also valuing of the principles of cultural relevance that had been the framework of the course philosophy, and communicated that these ideas had developed over the course of the semester. My analysis sought to examine how these ideas, as well as ideas about the physical concepts of the course, had developed through the course dialogues.

Analysis

The analytical processes used to address the research question – *Within the context of a physics course designed to be culturally relevant, how did students make meaning of physical concepts through dialogue?* – were carried out iteratively, narrowing the focus of the analysis with each iteration.

The first lens through which I attempted to interpret my data was the Ladson-Billings' (1995a) criteria for cultural relevance, adapted for science classes, according to which the curriculum would:

1. allow students to experience success with science learning;
2. recognize that students have a valuable scientific heritage associated with their culture; and
3. support them in challenging the status quo within the field of science.

During my first pass through the data, I looked for ways that these criteria were manifested in course dialogues. In discourses that I led, I looked for ways that my communications of pedagogical decisions helped establish an environment that supported student success in the course, welcomed cultural interpretations of science, and challenged traditional power structures. For discourses led by the students, I looked for evidence that students were experiencing success (i.e. developing conceptual understandings), drawing from or relating their learning to cultural concepts, and developing a critical understanding of the relationship between science and society. I developed the following list of evidence I intended to look for in the data that related to this lens, as well as highlighting the importance of storytelling as a tool for learning:

- How students used connections from their lives and previous knowledge to inform and give life to what they were learning;
- Atypical discussions for an intro physics course that highlight high-level understandings of physical concepts (makes the case for the value of the culturally-relevant course structure and giving voice to student thinking);

- How students' stories demonstrate the level of conceptual understanding they had developed;
- Personalization of the content;
- Examples of the students honoring their cultural heritage;
- Examples of the culture being used to make the content meaningful;
- Examples of the content being used to underscore the culture;
- Cultural content being interwoven with course content;
- Cultural understandings of physics that would not be common elsewhere;
- Unique ways in which the course goals and college goals were addressed;
- Examples where the course philosophy were brought to life; and
- Storytelling in other manifestations.

Once this evidence was compiled and all the data pertaining to the categories were identified, I selected out all excerpts of dialogue that I wanted to keep for future analysis, separating all important meaning-making moments from less pertinent dialogues such as small talk, off-topic talk, and procedural talk. From this reduced dataset I created a series of documents, one for each class transcript as well as all interview data and any pertinent reflections, to send to the participants and TOCC for their review. If there was anything in this data that a reviewer did not want included, they were to let me know. There were no calls for removal of any of the data, for one because the class did not emphasize sensitive cultural information to a significant degree, but also because the bulk of even this reduced body of data was immense.

Using the three criteria of culturally-relevant curricula as an analytical lens had been a useful first step, but it did not fully capture the story that was emerging. The second iteration of analysis involved seeking out evidence of dialogues in which meaning making around physical concepts took place. As each excerpt of dialogue was identified, it was associated with interpretive notes on its significance relative to the research question, along with an identification of its general topic, the class session in which it took place, and the student or students involved. These dialogues and notes were then sorted by physical concept.

The third iteration of analysis entailed synthesizing the data and notes for each physical concept. The data were examined across each student, over time, and with an emphasis on the personal, cultural and philosophical[2] funds of knowledge that the students brought to bear for each topic.

Kenny (2000) spoke of the importance of keeping the participants' words and stories at the center of the report of the findings, and Kovach (2009) considered participants' stories to be key for shifting the power for controlling the research to the participants and their communities. Smith (1999) wrote, "Indigenous communities have struggled since colonization to be able to exercise what is viewed as a fundamental right, that is to represent ourselves" (Smith, 1999, p. 150). Thus the importance of opening the door for students to speak for themselves in this work. As well, Wilson (2008) wrote that remaining faithful to the words of the participants and the researcher, who is also

[2] My use of the term "philosophical" to characterize these connections is a departure from the way that the field of philosophy would use the term. Though I apologize for coopting the concept, "philosophical" was the best descriptor for the spiritual, intellectual, and emotional ideas the students talked about in these instances.

inevitably a participant, fulfills the Indigenous research goals of authenticity and credibility (as opposed to Western-oriented goals of validity and reliability). Rather than speaking about or for my students in reporting the results of my analysis, I hoped to let the students' voices shine through and to highlight their ingenuity.

In order to showcase the students' voices, I kept in mind Wilson's (2008) summary of Tafoya's (1995) Principle of Uncertainty; "The closer you get to defining or explaining an idea, the more it [loses] its context. At the same time, the more the context of an idea is explained, the further you get from its definition or focus" (p. 99). The relational quality of Indigenous knowledge requires that its interpreter is provided with the context from which the knowledge arose; this has a significant influence on the way that the results of Indigenous research are presented. In her analysis, Kovach (2009) presented what she called "condensed conversations" that encapsulated a dialogue. In the book resulting from his dissertation research, Wilson (2008) used what he called a "composite conversation" to communicate the ideas he wished to discuss. The composite is pieces of conversations with different people that took place at different times, woven together; this chapter served as his analysis of the information gathered from each of his participants.

The results of the analysis that I present in the next chapter relied on a similar method; longer excerpts of dialogue were pared down from much longer discussions that included multiple sidebars, interruptions, false starts, repetitions, and so on. The sequence of the utterances was not changed, however, so the logic of the dialogue holds. These excerpts condensed the thoughts about a topic shared by the class, and by the students in particular.

Conclusion

In this chapter, I have summarized the methods used in this study, including my positionality as a researcher, the qualitative and Indigenous methodologies that underlay my decisions, the processes of obtaining approvals for the research and developing the course, an overview of the course itself, and an explanation of the data collection and analysis procedures. In the following chapter, I present the results of the analysis.

CHAPTER 4: RESULTS OF ANALYSIS

Introduction

Throughout the semester, the students engaged in dialogues and mini-storytelling events that related to the topics of the course. The research question with regard to these events is, *Within the context of a physics course designed to be culturally relevant, how did students make meaning of physical concepts through dialogue?* This chapter analyzes the approaches students took in learning physics, separated by specific content areas from the course. At the end of the chapter, I discuss the students' individual journeys with regard to their development of understandings of the nature of science.

Making meaning of physical concepts

Velocity and Acceleration

Motion (mechanics) is a central concept of introductory physics courses to which, it can be argued, all other topics can be tied: momentum, impulse, kinetic energy, molecular energy, and so on. As such, it is typically one of the first concepts that is taught in an introductory physics course, and this was the case for our class as well. Introduced early on, the topic of mechanics was revisited frequently across the first half of the semester. Meaning-making dialogues related to the central mechanics topics of velocity and acceleration were identified in the 3rd through 7th class sessions, again in the 12th session, and during the final in the 14th session. Six of these dialogues took place with Dylin, two with Drennan, and three with both students, for a total of eleven dialogues.

Velocity is not a difficult concept to grasp, as it is something we experience on a regular basis, though usually under the more common name of "speed". Acceleration is more conceptually difficult because although we do experience it on a regular basis, it is less identifiable, and the math for calculating it is more abstract. The students drew upon their funds of knowledge related to astronomy (or science fiction), driving, and football to make sense of these topics; Drennan's culture and Dylin's philosophical inquiries were additional resources that the students drew into the class.

In the course of what was essentially a math lesson about scientific notation (3^{rd} class), the students and I were going over a problem about the speed of light, using the concept of velocity to determine how far light can travel in one second in space. In the course of this discussion, the students introduced a "wondering" about travel at the speed of light. The wonderings introduced by each student – Dylin asking about why travel at light speed is impossible, and Drennan making a statement about relativistic mass and fuel – are both thoughtful and logical. This was likely not the first time the students had considered the topic of travel at light speed, with their interests in science and science fiction, but this topic introduced a space where they could insert their interests into the class and come to conclusions based on the physics they were learning.

Me:	[summarizing the calculation] Feel free to be dumbfounded with the large number. So that's how far light will travel in the course of 1 second: it will go 186,000 miles in space.
Dylin:	Is that why they say light speed is impossible?
Me:	For anything but light to go light speed….Once you start trying to get mass to go that fast you get relativistic effects, so the mass increases, so it's increasingly heavy.

Drennan:	So wouldn't it be like…there's no way, because mass is heavier so it takes more fuel...
Me:	Infinitely more fuel. Once you get to infinite you're done. You can't ever have infinite fuel.
Drennan:	Isn't light speed more like a measure of distance?
Me:	Well it's distance per time, yeah. So like a light-year is not a measure of time, it's a measure of distance. It's how far light can go in one year.
Dylin:	So in order to travel back in time you'd have to go faster than the speed of light.
Me:	[laughs] I don't know. Maybe, but I don't know. You'll have to ask somebody smarter than me about that.

The students' experience as drivers served as a useful fund of knowledge for learning about velocity and acceleration. The dialogue below (3rd class) was spurred by Drennan's question about the definition of velocity, which we were able to construct as a class by building on the students' knowledge of speed. The common unit for a car's velocity, miles per hour, was a springboard for deconstructing its components, which are two of the three components of linear velocity. The dialogue was Socratic in nature, with me as the instructor leading the students toward the answer through questioning. The class as a whole had the necessary pieces of knowledge to define velocity; these pieces just needed to be brought forward and put together to create the whole.

Drennan:	And all the velocity is… the same thing, right? Like the definition of velocity.
Me:	You remember what it is?

Drennan:	Isn’t it just the speed of something going?
Me:	So how do you figure out what the speed is? What’s an example of a speed?
Dylin:	Miles per hour.
Me:	Miles per hour, so what do you have? Miles is what?
Dylin:	Distance.
Me:	And hours is?
Both:	Time.
Me:	Distance and time. So how fast you go in how much time. So that’s speed, but velocity, it’s speed and what?
Drennan:	Trajectory?
Me:	Trajectory being?
Drennan:	I don’t know, where you’re going? [laughs]
Me:	Where you’re going. Direction. So velocity is speed in a direction.

We were similarly able to co-construct the concept of acceleration using the students’ driving fund of knowledge. The dialogue below (4th class) again stemmed from a student’s question and led into a Socratic dialogue; it demonstrates how Dylin constructed the concept of acceleration built upon his knowledge as a driver. He was then able to apply the concept of acceleration to understanding the meaning of “average velocity”, which he also appeared to contextualize with a driving scenario, although he does not explicitly say so; his description of accelerating to a maximum speed and then evening out could easily involve anything from cars to joggers to falling objects.

Dylin:	What if [velocity’s] not constant though?

Me:	Ok, that’s a very good question…What’s the word for changing velocity?… It’s a word you'll recognize from your car, if you’re a driver. What’s the word for the gas pedal?
Dylin:	Accelerator.
Me:	What does the accelerator do?
Dylin:	Makes you go faster.
Me:	What does the brake do?
Dylin:	Slow down.
Me:	What does the steering wheel do?
Dylin:	Changes your vectors.
Me:	Your direction, right. So there’s three ways to change the velocity of your car: you accelerate, you speed up; you brake, slow down; or change direction with the steering wheel. So what is acceleration?
Dylin:	A change in velocity.
Me:	A change in velocity…What are those three ways to do it? Same three ways you can do with a car; tell me what they are.
Dylin:	Slow down? Speed up? Or turn…change your direction?
Me:	That’s what acceleration’s all about. So what is average velocity all about, then?
Dylin:	Just what your average is, ‘cause when you're accelerating, obviously it’s gonna be different than when you reach your maximum speed and even out, so you gotta get an average.

The dialogue below (4th class) is distinctly different from those above in that it flowed from an open-ended question rather than being directed by the instructor; it is similar, however, in that it also drew upon a student's fund of knowledge from driving. In this case, Dylin was making meaning of velocity by applying it to his own personal experience of having a car accident. Dylin's car accident was a memorable and meaningful application of physics in his life, and as such it was a fund of knowledge that he drew upon again and again in our lessons about the physics of motion.

Me:	What do you actually use [the concept of velocity] for? Where is it meaningful?
Dylin:	In cars? I mean, I got in a car accident. So looking at how fast was I going, you know; the car had [impact], which means it was crumpling, which takes some of the velocity away before it gets to you, depending on what type of vehicle you've got…That's pretty important when you're buying a vehicle, like how safe is it gonna be, do you know how fast do you travel, does it have airbags, all that stuff.

For Drennan, language connections were especially salient. Although I had been tasked by the Himdag Committee with incorporating as much of the O'odham language as possible, my attempts to do so were not as successful as the language integration by the students themselves, particularly Drennan. The application of these terms from the O'odham culture sparked interesting philosophical discussions with Dylin, some of which will be elaborated on in later sections, but his interest was not in the language itself. However, because Drennan was an O'odham speaker, he frequently brought the language into the classroom, and the language gave him leverage in learning science. A dialogue from the 7th session with both Drennan and another O'odham-fluent student (not part of the research and thus not included in the data) about "speed" in the O'odham language was used to provide a context for the concept of velocity. I asked the students to describe velocity to an imagined O'odham speaker using the local language, and I helped the best I could to follow along and interpret – much like a student in a physics class might do. This was Drennan's chance to teach me the language while thinking about how he might teach the concept.

O'odham understandings of velocity are similar, but not identical, to how physics conceptualizes the concept. Drennan identified two different terms for "speed" in O'odham – one which Drennan stated was "more terrestrial", and another that would be used to describe more abstract things like a storm coming or time going by. He found ways to distinguish faster and slower-speed objects, and a way to quantify the speed. From what Drennan said, O'odham people would be concerned with how fast something was going and in which direction, just like a physical interpretation of a moving object. The reference frame would be relative to "us" or another person. This parallel added a dimension to the physics concept of velocity that was specific to Drennan as an O'odham language speaker.

Me:	How would you explain what speed is to somebody who has never seen it before?
Drennan:	Well I guess first of all I'd show them. Show them something, like throw a ball. 'See, this isn't going that fast.' Kind of velocity is how fast.

Me:	What's that word that we said, what's that O'odham word for speediness, for fast?
Drennan:	[word A] For 'fast'. Like running fast.
Me:	How would you use that in a sentence and can you translate it for me? Say talk about a bunny or something.
Drennan:	A bunny. [phrase with word A] 'The rabbit is running real fast.' It's more towards like, more terrestrial.
Me:	Okay, so running on the ground. How about a plane?
Drennan:	A plane I guess you'd have to use [word B].
Me:	How about like, what's something else even more abstract than that? Like 'a storm is coming in real fast.'
Drennan:	We'd probably say [word B]. Like it's coming towards us or coming near us.
Me:	How about…'time's going by fast'?
Drennan:	[phrase with word B] It would probably use that same word.
Me:	Interesting! So [word B] is kind of the 'going fast' word. [word A] is more like running, or, on the ground. Now how would you…quantify that?
Drennan:	[phrase with word B] Yeah, just say the number and how fast.
Me:	Okay. So if someone was asking you, 'well how much faster was it going?' You would tell them that in numbers and units, right?
Drennan:	Yeah, but you'd have to time it first.

Me:	All right, so that's what we're talking about with velocity. It's a number and a unit, and then velocity is also a direction, so it's going east, it's going up, it's going left, you know.

Both students, and especially Dylin, entered into discussions of the philosophical considerations of physical concepts readily and often on their own initiative. The topics they choose to incorporate were often not ones that an instructor would tend to include in a physics course, but they were naturally interesting to the students. In the excerpt below (4^{th} class), which was imbedded in a fairly mundane discussion about velocity, Dylin called into question the physical notion of "constant velocity". Constant velocity is a construct that only makes sense within a particular frame of reference, as I described in this sequence. Dylin posed a thoughtful, critical question – how realistic, and how useful, is this construct when everything undergoes acceleration all the time?

Me:	So if your average velocity…is not equal to your instantaneous velocity, it must mean that you've done some kind of acceleration.
Dylin:	But wouldn't you say that all velocity has to have acceleration? It has to have accelerated. Now it might end up as a constant, but it had to have accelerated at some point, right? It had to be positioned at one point, at some time…it had to start somewhere.
Me:	The thing about motion is that it's all relative…If I am sitting on a train and I'm throwing a ball up into the air and catching it in my hand, all I see is the ball going up and down, up and down. Someone watching from outside, sees

the ball going like this [in an arc]. So depending on your frame of reference, you will see or you will experience different velocities, different accelerations.

Dylin: So this goes back to what we were talking about before.

Me: It somewhat does. What we talked about before, for those of you who weren't here, is that…everything we do in science depends on our perspective. Because your perspective influences what you see, how you think about it, how you explain it…so this is kind of getting at that same idea, where things are relative.

Dylin: [Can you] give me an example of what wouldn't have an acceleration that we would calculate right now?

Me: It really just depends on your frame of reference because the time is arbitrary, too. We're not always talking about time [from] the beginning of the Universe, we're talking about time, like, ok, I say, 'it's noon; that equals zero.'

Dylin: If it starts rolling and then [we] said 'go', it's already in motion, there's no acceleration, [if] it's at the same speed, anyway.

Dylin suggested the connection between frames of reference and the influence of culture ("what we were talking about before"). This connection would not have come about with Dylin's suggestion. In my reflection on this class, written shortly after the class ended, I wrote, "Today in class I got into some cultural relativism and related it to [frames of reference]. Novel concept!...I hadn't even thought of that connection until one of the students brought it up, but it makes a lot of sense. Broadly speaking, the way you look at the world affects the way you see it. That may be the influence of your culture, gender, race, SES [socioeconomic status], age, etc. on the questions you ask, the observations you make, the conclusions you come to, the interpretations you make, and so on. And it may be the influence of your position on the motion you see and the measurements you make. They're such perfect analogies for each other that I'm surprised I never thought of it before."

Dylin's comment that all things must have accelerated if they are in motion was juxtaposed with the fact that, if an observer is just arriving on the scene while a moving object goes by, they may well observe it at a constant velocity even if they assume it may have accelerated in the past. Velocity and acceleration are relative to perspective, so we must set a frame of reference in order to interpret motion. Dylin revisited this idea in the next session in his interpretation of the meaning of motion in a negative direction. The excerpt below (5th class) shows Dylin defining a frame of reference to make sense of negative velocity.

Dylin:	So velocity less than zero…does that mean it would be accelerating in reverse?
Me:	Reverse meaning what?
Dylin:	[laughs] Backwards?
Me:	Right. So if you have some arbitrary zero point, it's going away from zero toward the negative numbers. That's all it's basically saying.

Dylin:	If it's going negatively, wouldn't that just be positively in the other direction? You could say hey, if you wanna go in the negative direction, you're actually just going south.

By the end of the semester, the students' fluency with the concepts of velocity and acceleration had greatly improved, as evidenced by their performance on the final exam. The excerpt below (14th class) contains their responses to Question 1, Part J of the final, which asked them to describe where they saw acceleration take place in the marble drop activity, in which the students were asked to design an experiment to elucidate the relationship between the height of a dropped marble and the distance it displaced a cup at the bottom of its trajectory.

Me:	Where do you see acceleration?
Dylin:	When [the marble is] let go, or dropped…It increases its speed. And also when it hits the cup.
Me:	Okay, then what happens to it?
Dylin:	It decreases the speed of the marble.
Me:	Good. How about you, Drennan?
Drennan:	I mean, even the cup, it would be accelerated because it was at rest and it was pushed because of the force….But then since it gets caught here, or maybe because of the shape, it causes it to spin…so it also accelerates there.

In their responses, the students identified each of the three types of acceleration based on the three ways that velocity can be changed: increasing speed, decreasing speed, and changing direction.

To aid them in the process of learning about velocity and acceleration, the students drew upon funds of knowledge from science fiction, driving, the O'odham language and culture, and even philosophical considerations about the importance of perspective. In so doing, they created contextual worlds for these mechanical concepts that gave them meaning beyond mere definitions from the textbook.

Momentum

Momentum is a related topic from mechanics and is a measure of an object's inertia in motion (i.e. how difficult it would be to stop or redirect it), dependent upon its velocity and mass. Momentum provided many opportunities for the students to build their conceptual maps using dialogue, due to its familiarity and application to everyday life. The term "momentum" is not uncommon in normal conversation, and although the students did not likely understand the concept from the perspective of a physics student at the beginning of the course, they had a diversity of experiences and background knowledge that they were able to re-interpret from this perspective. As the students learned about the concept of momentum, meaning making took place in dialogues through students' connections to out-of-class content from science shows, personal experience, pop culture, sports, and games.

Discussions about momentum took place across seven class sessions throughout the semester: two near the start of the semester, and five from the second half of the semester. Thirteen distinct class dialogues were identified as meaning-making events: five with Drennan, five with Dylin, and three with both students. As with velocity and acceleration, these dialogues largely entailed the students bringing the concept of momentum into different scenarios and practical examples to either explore or demonstrate knowledge of the concept. Analyses related to each student's meaning making around the concept of momentum are presented below, followed by an analysis of dialogues when both students participated together.

Drennan

Drennan already had a familiarity with momentum when he began the class. Because his particular interest was space and astronomy, connections to solar system and galactic objects were pertinent to him. His first attempt at explaining momentum in the first class drew from his personal repertoire to demonstrate his physical understanding: "Like an asteroid's momentum, it grows as it goes past a planet because of its gravity." He was aware already of the relationship between momentum and velocity, as implied by his description of the asteroid speeding up as it approached the planet, thus increasing its momentum.

In the 2nd class, Drennan reiterated this notion when he stated, "Momentum is when…the energy of something goes up while it's going, like a car rolling down a hill, it goes faster and faster and faster." We were able to build on Drennan's existing knowledge of momentum and extend it to include the other essential component of momentum, mass, of which Drennan also had an intuitive understanding; when I asked him what he expected would have a greater momentum, a more or less massive object, he correctly chose the more massive object. We used Drennan's intuitive understandings as the backbone of our discussion in order to construct the physical formula for momentum ($\rho = mv$, or momentum equals mass times velocity).

Drennan:	Momentum is when, like, the energy of something goes up while it's going, like a car rolling down a hill, it goes faster and faster and faster.
Me:	Energy built up by going; I like that…So what you were saying is, it goes faster and faster? What was the, kinda the phrase you would use to describe what's going on there…there's a certain phrase that we use in common language.
Drennan:	Um, building momentum?
Me:	Exactly. Building momentum. So in other words, momentum is going up. So from that, what can you, what can you infer? Momentum is increasing; if it's going faster and faster, momentum is going up. So as velocity goes up, momentum goes up. … So then you must have velocity in the equation in the formula for momentum. Because they're proportional: as one goes up, the other goes up. Ok? …What would you say about the momentum of a train and the momentum of an ant going equally fast… Which one would you say has more momentum?
Drennan:	The train would have more momentum, because it has more mass.
Me:	More mass. So as mass goes up, momentum goes up. … So you've just derived the formula for momentum. Momentum equals mass times velocity…As mass goes up, momentum goes up; as velocity goes up, momentum goes up. So if you could somehow build mass, you'd also be building momentum as you were going.
Drennan:	Yeah, like the snowball?

Drennan's final comment confirmed his strong conceptual understanding, as his example of the momentum of a snowball (rolling down a hill) would increase due to increases in both its mass and its velocity.

Later in the semester (10^{th} session), I asked Drennan again to explain momentum; this time, his explanation was much more complex. He said,

> It's like the force…it's kind of considered like the outcome of an action…it's an equal reaction, if you throw it…let's say it hits a wall or it hits the pins, it's giving a little bounce back but it's actually more transferring, transferring the energy more than anything.

Although this explanation is much less clear than his previous ones, there were several ideas tied up in this statement that demonstrated that his mental map of momentum had gained a great deal more detail. In this case, he was looking at momentum not just as a quality of an object defined simply by its mass and velocity, but as an object's capability to make something else happen if its momentum comes into contact with another object. With this explanation, Drennan connected momentum to Newton's 3rd law ("equal reaction") and to conservation of energy ("transferring the energy"), and he used these other concepts to help him frame what he was actually describing, which was the conservation of momentum. The scenario he created, which appears to be about bowling (although he never specifically mentions bowling nor a ball, it is implied), has a ball with a given momentum coming into contact with pins or a wall, where it will either bounce back per Newton's 3^{rd} law of motion (the wall pushing back on the ball and "giving it a little bounce back") or "transferring the energy" to the pins.

His mental framework for momentum at this point of the semester included other ideas that he had learned about since the start of the course, and although he struggled with putting it all into words, it was mutually consistent and accurate.

It was not surprising that Drennan would look at momentum as "energy", though in physics they are different quantities. Both are abstract, yet we tend to have a better common-sense grasp of energy, or at least use the term more frequently in everyday conversation. Thinking about momentum as energy assisted Drennan in wrapping his mind around the concept. When he and I were discussing the application of conservation of momentum to a car crash scenario in the 12th class session, he can be seen using energy and momentum interchangeably, yet also using energy to help him understand momentum. To start this excerpt of dialogue, he asked, "What if the car exploded?"

Me:	If the pieces shoot out? All those pieces had to add up to the momentum that it started with.
Drennan:	Okay, so all the energy…is still there, it's just been split up into different directions and different things.
Me:	Yeah, the momentum for sure. The energy, some particles are going to have more energy than others.
Drennan:	Would that be the same thing with electricity? Would it be a shock? ...let's say, right just then it shocked me and it's giving me the momentum and I do this [knocks into something], the momentum is still transferred because I knocked this over.

Me:	If it was motion, it's momentum, yes. Electricity is…if it travels to you then you transfer it to the ground. Or you transfer it to the air. You transfer it to, you know, somebody else.
Drennan:	Like a lightning strike comes down from the clouds and to you and it keeps going.

In this interaction, Drennan used his idea about energy, which he associated with electricity, to expand his construct of conservation of momentum, where getting a shock jerks his body and causes him to transfer some of his momentum into another object. The overlap between these two concepts lends itself to an analogy between them: electricity is transferred just as momentum is transferred, like a lightning strike that "comes down from the clouds and to you and it keeps going."

Dylin

As previously mentioned, Dylin had a personal connection to the physics of collisions from his car accident, and learning about momentum and impulse gave him the language to talk about it. In the 10th class session, Dylin related a story about trains that he saw on a show called Crash Science, drawing in the class concepts of momentum and impulse – the outer layers of trains would crush upon impact and absorb the force of collision, protecting the people inside. He then drew upon the pop culture reference to describe his own direct experience of getting into a car accident, noting how the car behaved under the conditions of the collision:

> Like when I got in my car accident, the car did exactly what it was supposed to do; it totaled itself. So, whatever, you know, when the impact is, it automatically crashes in,

even if you're going 30 miles an hour; a lot of the cars nowadays will [have a] crash zone.

In the next class session, we were discussing impulse, which relates to the force and time needed to change an object's momentum (i.e. an object with higher momentum will collide with more force, but if the impact can be spread out over more time the force will decrease). I asked Dylin to give me an example of when impulse would be used in the real world, and he again drew upon cars.

Dylin:	Say driving in the city, there's a red light, you kinda know your car, you know you have this certain amount of feet when to start braking. You're not gonna be going 55 and then wait till you're two cars away from the other car to start braking. So you're gonna start braking when you know you're gonna have enough time to actually stop.
Me:	If someone comes in front of you and they slam on their brakes, what do you have to do?
Dylin:	Slam on the brakes.
Me:	With a lot more…
Dylin:	Force.
Me:	Force, because you have a lot less…
Dylin:	Time.

This concept was particularly relevant to Dylin because it provided another perspective on car crashes. Dylin was able to apply the concept of impulse to what he experienced in his accident. In the following excerpt, he elaborates on car crumple zones using some of his physics vocabulary (“impact”, “force”) and utilizing the concept of impulse to explain how crumple zones work.

> When you…hit the ground, with the impact, when you bend your legs it takes some of that force away. [I]t’s like the crash crumple zones in the cars. They buckle, they take some of the force away; you’re still getting some force but it should [be] lesser. You might break your legs, but it’s better than breaking your back.

Dylin’s other fund of knowledge related to momentum and impulse was his experience as a former football player. As with the car crash, gaining a background in mechanical concepts like momentum gave him a new lens for interpreting these experiences. In the 11th session, I posed a similar question to Dylin that I had posed to Drennan in the 2nd class, asking him to identify a commonly-used phrase with momentum; he talked about how sports teams are said to be “gaining momentum”. In this dialogue, we use Dylin’s phrase, with a nod to his story about trains from the previous week, to elucidate the conservation of momentum (if one thing gains momentum, something else must be losing it).

Dylin:	Like they’re getting momentum, they’re getting…better, the luck’s on their side, or they’re getting faster, whatever it happens to be. They’re gaining momentum.
Me:	What does that mean to the other team, if that team is gaining momentum?
Dylin:	They’re losing momentum.
Me:	So how are they thinking about this team [the one gaining momentum]? Are they gonna be easy to defeat or hard to defeat?

Dylin:	Harder.
Me:	Ok…harder to change their motion.

Football was also useful for Dylin when learning about collisions. Also in the 11th session Dylin came up with a scenario involving a linebacker tackling a runningback. In his mind, he knew exactly how the play would unfold and what would happen when the two players collided, so we built upon this scenario and added realistic numbers to the mass and velocity variables based upon Dylin's estimates. We then ran through the scenario mathematically to determine what the numbers said would happen when the players came together, validating Dylin's prediction based on his mental model.

Dylin gained an appreciation for the physical knowledge of football coaches by exploring the concepts of momentum and collisions. He talked about how coaches would advise players not to lose momentum:

> They don't want them to stop, and lose all that momentum and have to start over again. So they teach you how to turn your hips and how to shuffle your feet, so you're slowing your momentum down, but you're not stopping it, so when you're actually completed your move to go a different direction, you still have momentum going with you so it's a lot easier to go back to full speed.

He also talked about the other players trying to interfere with their opponents' momentum:

> The defensive lineman is rushing the quarterback; the offensive lineman, their job is not to tackle 'em or crush 'em, their job is just to stop the momentum, or shift it. Like a lot of

the offensive linemen, when the defensive ends will be rushing around the end to hit the quarterback, they will let their own momentum take them.

When Dylin referred to its being “easier to go back to full speed” by maintaining one’s momentum, he was accurately describing the relationship between momentum and velocity, and when he talked about the offensive linemen letting “their own momentum take them”, he was demonstrating an understanding of momentum as a vector with a directional component. Dylin’s football knowledge helped him to contextualize the physical concepts he was learning, and his newly-gained knowledge of physics helped him to interpret his football knowledge in a fresh light.

Both students

One of the notable elements about the atlatl activity, which will be discussed in more detail in a later section, was that it gave the students an opportunity to exercise their knowledge of momentum. During the 8th class, the students were engaged with using the atlatl and also discussing how it works. Dylin commented that the atlatl was different from hand-throwing a spear, where you could continue following through with your arm; with the atlatl you need to stop the arc of your arm at the right point so that the dart is aimed properly. Dylin stated, “You’re kinda killing the momentum then,” because your velocity comes to a stop. Drennan argued that this would not be the case (if, for instance, we had actually become more skilled at using the atlatl); “I think you roll through it though, you throw it and you kinda roll through it and it automatically leaves.” In other words, the velocity would not go to zero, because you would follow through with your arm and continue exerting a force to accelerate the dart. The students drew upon their knowledge of momentum, among other concepts, in order to debate and build understanding about the mechanism of this ancestral tool.

Another event around the topic of momentum occurred across several class sessions. Dylin managed to stump me with a question during the eleventh session about how momentum is conserved if a car crashes directly in a mountain. Intuitively, he predicted that the mountain would not budge, and the car would not bounce back with the full velocity it had started with, so some of the car's momentum was being lost – how can that be? At the time, I could not give a satisfying answer to this question, so I had to consult with a more physics-savvy friend after class. This conundrum became an opportunity for learning through dialogue with both students, because Dylin was not in class the next session when I explained what I had learned, so Drennan had to explain it to Dylin when they were both together again. Thus, a question asked by one student was answered by the other student (and me) in the last class.

Me:	So I don't think you [Dylin] were here when we [Drennan and I] were talking about your questions. We were talking about when you hit the mountain with the car, how is the momentum conserved? Can you [Drennan] explain that? Do you remember what we talked about?
Drennan:	The momentum will cause, like the pieces will keep flying farther and farther. And some pieces are smaller and some pieces are bigger and the bigger pieces won't fly as far as little pieces. But if you were able to capture all the pieces together, then measure the energy, it would still all be the same, it would just be divided into little, more little pieces.

Me:	Yeah. So that was a piece of it, and then there was the crumpling of the car: the momentum would be going to reversing direction of some of that part of the car. It's going to go into heating up the molecules, which is the momentum of molecules. So it's going to heat up the car, heat up the mountain. It's also going to compress the mountain a little bit. So all of that added together will equal the momentum that it started with.
Dylin:	What if it's not a car, it's like a titanium rod, so it's not gonna shatter?
Drennan:	Wouldn't it all transfer to the mountain because the titanium will be stronger than the rock?
Me:	It's going to heat up the mountain. It's going to heat up the rod. Does the rod go through the mountain or not? What were you thinking? That it's just going to hit it and they're both going to stop?
Dylin:	Yeah. Well, not stop. It may bounce off a little bit but not enough to where it's gonna make it go, you know, 50 feet back.
Me:	I think it's probably going to deform the mountain…it's going to make a hole, probably, or a collision. So that's gonna take up some momentum. It's gonna heat up both sides.
Dylin:	So the same thing.

Interestingly, this explanation had a large impact on Dylin (no pun intended), as he went on to use it in his own explanation after class during his final class presentation.

Me:	When the bullet goes through the watermelon, does it change its momentum?
Dylin:	It slows down, even if it's miniscule, it's gonna slow down a little bit and the

	one with the hollow tip is gonna slow down much more because of the surface.
Me:	How come? What happens to the kinetic energy?
Dylin:	It gets transferred to the watermelon.
Me:	Okay. And what does the watermelon do?
Dylin:	The watermelon gets blown up. You can see, the kinetic energy from the hollow tip, obviously more of it got transferred to the watermelon because it exploded. So if you get all those bits and pieces together, put them back, it'll still equal the momentum the bullet originally had. If you get the standard one, there's not all those bits and pieces so the energy still got transferred, but not as much. So that one would still have more momentum.

Despite the fact that Dylin had only recently discussed the conservation of momentum in the classroom with Drennan and me, he drew upon this explanation to describe the physics of different bullet impacts in his presentation. Granted, he did not have long to forget what we'd discussed, but his ability to apply it in a different situation suggests that he understood it more than superficially.

The excerpt above provided strong evidence that the collaborative teaching and learning through dialogue was an effective pedagogical strategy. Although the cultural connections and philosophical considerations were not prevalent in the students' dialogues about momentum as they were with velocity and acceleration, they were again drawing in examples that were personally meaningful to them and using these to frame their understandings.

Gravity

Gravity is one of the four fundamental forces of the Universe, and is the one with which we have the most everyday experience. Understanding gravity is essential for understanding the motion of projectiles on Earth and celestial bodies in space; these two very different contexts give gravity a different flavor depending on which frame of reference one is using to look at it, which provided for interesting discussions with the students. Gravity was discussed in nine different sessions across the whole semester, mainly in the latter half. Sixteen dialogues were identified for gravity, half of them with Dylin (eight dialogues), seven with Drennan, and one with both students. The dialogues in which the class discussed gravity showed the students grappling with ideas that are not straight-forward and which demand a great deal of mental effort to understand.

The students each took very different routes through the learning of gravity. Dylin's journey is characterized by connections to science fiction, as well as a struggle to reconcile the incongruence between his intuitive understandings of gravitation and the physical discourse. Dylin's dialogues focused on posing questions in order to delve into the nature of the concept. Interactions with Drennan similarly explored questions and scenarios to build a deeper understanding of gravity, but with much less interference from conflicting models. Drennan's journey involved an exploration of physical applications of gravity, designed (by Drennan) to help him wrap his mind around its more exotic nuances.

Both students utilized classroom dialogues to create and investigate scenarios where they could test their ideas, though in all cases, the gravity dialogues in which meaning making was evident were one-on-one with me and a single student. Because the students' approaches were so different, and because each student's interactions took place in different class sessions, the analyses for Dylin and Drennan are presented separately below.

Dylin

Dylin mentioned during the course that he enjoyed thinking about gravity, which he was able to connect to many of his interests, such as military weapons, space travel, football, and science fiction; these connections allowed us to explore the facets of gravitation across an assortment of contexts. Dylin's familiarity with the Star Wars series of novels was a particularly fruitful fund of knowledge for deriving the two key components of the formula for the force of gravity, mass and distance. Examining gravity in an astronomical sense came naturally to him because he was able to apply what he learned to Star Wars storylines; prior to the excerpt below (5^{th} class), we had been discussing the fact that gravity is caused by mass, and Dylin extended this thought to consider how the force of gravity would be different on planets of different masses. He related this to Star Wars characters' experiences.

> They have this a lot in Star Wars. They have creatures, you know, whatever, they come from their home planet…So this guy, you know, comes from this planet, he goes to other planets and he's super-strong because the gravitational pull on his planet is a lot stronger, so when he goes somewhere else there's a lot less resistance, so he's superhuman. But then he goes back to his home planet and then vice versa, they go to his planet and the Jedis are like 'ugh, I can hardly move!'

Relating planets of different masses to vicariously experiencing the planets' gravities through these characters helped make the connection meaningful for Dylin. Similarly, another Star Wars plot device helped him to scaffold his understanding of gravity toward more complexity. The following story Dylin shared (11th class) worked as a framework for constructing the formula for the force of gravity.

> In Star Wars, the creatures they're fighting, they use all natural technology…Instead of having shields…they manipulate gravity and they form a little black hole, so when they're shooting lasers, instead of a shield…they project those little black holes where the lasers go.

Black holes, which Dylin described as "sucking" things in if they got too close, were an avenue into viewing gravity as dependent upon distance, and ultimately for understanding it as dependent upon both mass *and* distance. In this excerpt, we discussed the interaction between gravitational force, mass and distance.

Me:	[A black hole] implodes to a single point in space.
Dylin:	So it doesn't lose its mass, it just makes the mass…
Me:	It concentrates it all in a tiny space.
Dylin:	This one little spot, and that's why …light can't get out, because…
Me:	It's too strong.
Dylin:	Instead of the Earth being this big with this gravitational pull, if it was that big, it would have a greater gravitational pull?
Me:	As you got close to it.

Dylin continued to ask “what if” questions to probe the nature of gravity; as his question about the Earth’s force increasing if it got smaller and denser demonstrates, he had already made the connection between masses and gravity and was now exploring the connection between distance and gravity. However, he was conflating the size of the mass with the distance from its center, and he was not yet seeing the interrelatedness of all three variables of mass, distance and gravitational force. From here, we went on to derive the equation for gravity and to talk about the constant G, the inverse square law, and how all masses, including people, have their own force of gravity. We discussed how, when Dylin stumbles out a second story window and falls because the Earth exerts a force on him, he is also exerting a force on the Earth, F_{Dylin}. His last “what if” question of this dialogue drew together all the components of gravitational force, in response to this idea.

> You know how, ok, Earth’s gravity in space, something’s floating, it gets a little too close and it’s caught, right? And eventually, it’s gonna fall. Does that work with humans? Can I stand here, and there’s a fly flying around, and pretty soon it has no choice but to get sucked in? Or if you get a large group of people huddled in a mass…

In the scenario above, Dylin was examining the possibilities of a world where all masses exert a gravitational force that gets stronger as you approach them. In space away from other large masses like the Earth, his scenario would work better, but his basic structure of a larger mass exerting a force on a smaller mass that increases as the distance shortens, and which accelerates that smaller mass and pulls it closer, was scientifically sound.

There was one particular of gravity that gave Dylin significant trouble, however: the universal acceleration due to gravity on Earth. The following dialogues reveal his struggles to make sense of the inconsistencies between his mental models and personal experience, and the model posited by the physics discourse.

Dylin initially began probing his own understanding of Earth-centered gravity in the 5th class session, where he prefaced the conversation with "Lemme ask you a question" about the physics of cartoons. He initially wanted to know if a person falling with a crashing plane could jump up and slow themselves down, which evolved into a discussion of whether a person or a plane would fall faster in the Earth's atmosphere. Dylin's expectations of what would happen in reality, as opposed to in an idealized situation where all things fall at the same rate on Earth, were correct and were in fact more accurate than the predictions of my simpler model. His model of free fall included the effects of air resistance:

Me:	So you think air resistance is gonna make that big of a difference?
Dylin:	Yeah. A decent amount. That's why we have parachutes. It catches the air, right…we increase our air resistance. So yeah, air resistance is definitely a factor, a big factor.

The fact that Dylin's model included air resistance and mine (representing the physical discourse) did not was a point of contention for Dylin. At first, Dylin seemed to give up on resolving the conflict, opting to defer to science:

Ok. I know it's probably true, because obviously, I mean, Newton and everyone doing this, obviously I'm not as, even as close to as smart as [them]…[but it] doesn't seem feasible.

This point of contention motivated Dylin to resolve it. He presented a scenario that demonstrated that the equation in question was incomplete and unrealistic because it failed to consider the very real effects of air resistance and thus terminal velocity, and as a result was inadequate to fully describe the physics of falling objects.

Dylin:	So if I dropped…a penny off the Empire State Building…it's only gonna reach a certain speed because of its mass, it's not gonna…do anything. So if I threw a tank over, you would definitely think the tank would hit first rather than the penny. Even though it's getting more resistance. Because it's got wider space, it's getting more air resistance, so they're not falling at the same rate.
Me:	The penny does reach terminal velocity faster. But if you dropped them both from two stories, they'd both hit the ground at the same time. If your air is not terribly thick. This is…the equations don't have anything to do with air resistance.
Dylin:	But how could they…but you have to. How can you say that things fall at 9.8 meters per second squared on Earth, because there's no place on Earth that doesn't have wind or anything else, so to say that would be incorrect. To say that everything, because of gravity, falls at 9.8 meters per second.
Me:	The acceleration due to gravity is constant, at the surface of the Earth.

Dylin:	Yes. But not everything falls at the same rate, when you include air resistance and everything else, which you have to when you're on Earth.

Following the lead of the text and the way that I learned physics, I was trying to isolate the effects of gravity on falling objects, while Dylin was attempting to unify the effects to create a more complete picture. Dylin's point of contention was a matter of perspective and of prioritizing holism over reductionism. In the following excerpt, we made the distinction explicit. My comments were referring back to Dylin's summary of the text, where the authors talked about focusing on the basic fundamentals of a physical scenario so they can isolate the most important effects. I had noted to Dylin at the time that this process can get out of hand.

Me:	This is why we take the book with a grain of salt….in the very first chapter when they were talking about modeling and how…the world is so complex that if you worry about the spin of the Earth and the spin of the Sun…
Dylin:	Yeah, I remember you said that.
Me:	So they simplify everything. Which is one way of looking at. You could also look at [it] as it's way too simple, and it's never gonna actually be that way, so why do we even look at it [like that]?
Dylin:	So you could say I'm right.
Me:	Yeah. [laughs] Yeah, you can. Sure.
Dylin:	I like that. [laughs]

Dylin became more comfortable with gravity after this short discussion. A few moments later, I was able to find a scenario in which the interfering variable of air resistance is *plausibly* absent, and the concept I'd been trying to convey popped right out to Dylin.

Me:	How about in the space shuttle? When they are at zero g. So they are at terminal velocity; they're free falling, right? And there's no atmosphere, there's no gases in the space shuttle, right? And they drop a hammer and a feather. Which one falls faster?
Dylin:	They fall at the same rate. [laughs]
Me:	Ok. Does that make sense?
Dylin:	Yeah, it makes sense.
Me:	Does it? I mean, is that what you would expect?
Dylin:	Yeah, if there's no….there's no air in there!

My follow-up question to Dylin in the excerpt above expressed my surprise that, in the absence of air, constant acceleration made sense to Dylin. I expected that his resistance was due to an intuitive sense that heavier objects fall faster because of the larger force of gravity, but this common misconception was in fact not the issue; it was indeed, as Dylin had insisted, the realism of the scenario that was lacking for him. When we deconstructed the way Western science approaches problems in the previous excerpt, what we managed to do, as Dylin interpreted, was to validate his perspective.

<u>Drennan</u>

Drennan, like Dylin, drew upon scenarios from astronomy to help him create a conceptual model of gravity, but he used these scenarios to explore different aspects of gravitation from those considered by Dylin. This was due in part to the fact that for

Drennan the issue of all objects accelerating at the same rate due to the Earth's gravity was unproblematic, or at least did not trigger for him the difficulties that Dylin went through. The following excerpt (7th class) followed an activity working with the formula for calculating distance based on velocity and acceleration; I had asked Drennan to apply these concepts to a lab activity using air-powered rockets that we had done previously.

ME:	This is our foam rocket. [diagrams the rocket's motion]…What's our acceleration?
Drennan:	…I don't know.
Me:	What's acceleration due to gravity?
Drennan:	Oh, is it the same? That 9.8?...If we do these type of things for a launch, it's always gonna be 9.8?
Me:	On Earth.
Drennan:	On Earth. No matter where or what it is it's always gonna be that?
Me:	It's an approximation…remember you were saying the gravity is stronger at the poles [than] at the equator? …So there are some variations on Earth.
Drennan:	Yeah.

Though working with the same concept that Dylin had struggled with, the constant acceleration due to gravity on Earth, Drennan accepted the scientific explanation without issue. My explanation, as a result, took a very different turn, exploring the nuances behind the "constant" element, something I never got into with Dylin. Granted, this was a different activity, so it would naturally go in a different direction, but the difference between the students was likely another contributing factor. In his interview with me after the semester, the constant acceleration due to gravity was one of the things that Drennan shared with his friends as something that he appreciated about learning physics.

Me:	What did you try to show them?
Drennan:	The one thing I kept pushing was the gravity, how everything falls at a certain percent, everything, everything. They're like "wow!" And just using that little thing, you can start a…problem. Yeah, like you can write anything down and pretty much figure everything out, just 'cause you know that little speed. Anything it is, just know the weight of something, where, how fast, how high it's going, and then you can just measure it out like that. And that was, that was pretty interesting. And it pertained to everything, like everything, now when I look at something, "I wonder if that falls, how long it's gonna take," you know? Now I just kinda look at that everywhere, like "wow, it's gonna fall real hard if it falls from up there!" or "it's not gonna hurt if [someone trips] and falls right there" you know? So, it was pretty cool. That's one thing I keep thinking about, you know, everything I look at.

One of Drennan's interests in gravity lay in its relationship to life. In the 12th class session, he introduced a series of scenarios exploring gravity, and tying it back to its effects on living things. The excerpt below begins with his asking about the physical relationship between planetary masses and gravity, as Dylin did as well. Similarly to how Dylin tied this fact to the Star Wars novels, Drennan speculated about the anatomy of life forms on these different planets – in particular, if animals would be able to float on a planet with lower gravity.

Drennan:	If the planet's bigger…[is] gravity stronger 'cause it has more mass?
Me:	If it's more massive yes. It doesn't have to do with its size but its mass.
Drennan:	Its mass…could the opposite be true? Like it could be bigger but not have as much gravity.
Me:	[If] it's got not that much mass really, but it's really, really big, it could be less massive than something else that could be smaller, but made of steel that's really, really dense.
Drennan:	Cool. I know that like a lot of human had to evolve to just gravity and stuff like that; that's why space is so hard for us…Are there creatures out there that have internal gas sacks…are there planets where whale-like creatures fly in the sky?

Drennan also seemed to view the fundamental forces of the Universe (gravity, electromagnetism, and the strong and weak nuclear forces) as different faces of the same phenomenon, even using their names interchangeably (e.g. referring to a "magnetic force" between molecules and between planets, 12th class). His holistic view of universal forces allowed him to draw connections between gravity and life. He stated in our 12th class lesson on gravity, immediately following my explanation that gravity is an important force in our Universe, "That's why we're held together and each of our molecules is like connected to another." A Western scientist may look at Drennan's comparison as a metaphor linking gravity to molecular forces (electrostatics), but to

Drennan they were the same, and thus gravity was to him an important part of what makes life possible.

From Drennan's comfort level with discussing gravity from an astronomical perspective, the astronomical examples he drew in, and the verbiage he used to describe them, it was clear that he brought a great deal of background knowledge about space into the classroom. He mentioned that physics was strongly tied to astronomy for him in the 12th session ("physics…always, for me, connected [to] the galaxy and stuff like that"), he adapted a quote from Carl Sagan for conversation in the 7th session ("we're made of star stuff"), and he introduced astronomical examples for momentum (1st class), energy (7th class), and of course gravity (12th class), among others. Drennan knew, for instance, that an object's force of gravity "would depend on mass" and "increase…as it gets close"; he also knew that, despite its huge importance on astronomical scales, gravity is a relatively weak force.

> I mean gravity is one of the weakest forces; even though it's one of the strongest, it's still not really…You can lift a penny off a table with a magnet, but gravity keeps us in orbit around the Sun, or [keeps] the planet, because [the planet's] mass is so small.

However, he was not merely regurgitating information from science specials and books; his statements in the 12th session dialogues suggest that he was synthesizing information presented in the dialogues, including his examples but also mine, to come to conclusions about gravity. Drennan introduced a "string of pearls" scenario to find out about more complex, and more realistic, setups in which there are more than just two bodies.

Drennan:	Our planets, what if each of them were the size of the Earth? Is it a combined number, or is it just like that small little bit next to that little bit next to that little bit? If they're all in a row together and then there's an object at a distance…would that object feel a pull from all of them combined, or just the one plus the one plus the one. Or would it just feel the last one?
Me:	The center of gravity…is like an average in space. So wherever most of the mass is concentrated, that's where you could call the center of gravity. It's the same as on Earth…we don't worry about how much we're being pulled by that mountain versus that mountain versus that valley versus that river, we feel like we're being pulled down toward the center of the Earth, always.
Drennan:	That will go towards this [drops an object] like this, because we're all being pulled down…

By manipulating his scenario through dialogue, Drennan sought to deepen his understanding of gravitation. I introduced the idea of center of mass, or center of gravity, in response to his inquiry, and Drennan reinforced this idea by demonstrating how a falling object falls straight down. He followed up by asking what it would be like if the Earth was more like a potato, possibly motivated by common descriptions of asteroids as "potato-shaped." We explored what the force might look like for that kind of shape. His conclusion statement at the end demonstrates that he was actively processing the information we discussed.

Drennan:	What if the Earth was shaped like a potato? Would there be more gravity towards the longer close parts 'cause they're closer to the center, than there would be at the edges?
Me:	Yeah, you have to look at what the average is. Say this side is denser than that side, so there's more mass on this side than that side. So if you were over here [on the less dense side], even though this is kind of down to you [perpendicular to the ground] you'd feel like you're being pulled that way [toward the center of mass].
Drennan:	So if I was walking like this on it, I'd lean.

Thinking of potato-shaped things and strange centers of mass, I mentioned an asteroid (Ida) with its own tiny asteroid moon (Dactyl), and we talked about how the density of the objects would affect the center of gravity.

Me:	So the way that [Dactyl] orbits is gonna be where that center of gravity is; it's gonna orbit around that center of gravity.
Drennan:	So if [Ida] is denser in the lower part, [Dactyl] will orbit around the lower part.

Again, Drennan drew a conclusion about the gravitational interaction based on this new information. He used his extensive knowledge from outside the class to spur discussions that extended on this knowledge, and he synthesized what he knew and what he learned into new understandings about gravity.

Summary

As with momentum, the bulk of the connections that students made with gravity related to their personal interests rather than their cultural identities. Like momentum, gravity presented opportunities for students to use their imaginations to create and manipulate scenarios where they could test their ideas – in the case of gravity, these scenarios typically took place in outer space away from the Earth's gravity and the interference of air resistance. Importantly, these imagined scenarios allowed the students to stretch their understandings and synthesize new ones that accounted for the knowledge they gained from them.

Explosions

From the very beginning of the semester, explosions were an example to which the students kept coming back. Explosions were, in fact, not a part of the official curriculum, yet they were introduced into the classroom dialogue with such frequency and enjoyment that they became part of the *de facto* curriculum. Because the students considered explosions to be such an important part of the class (though we actually did not explode anything intentionally), their connections to the physical content warranted analysis in their own right.

There were a total of fifteen instances of explosions being mentioned in the course dialogues, primarily at the very beginning (six mentions in the first four sessions) and very end (seven mentions in the last four sessions) of the semester. Seven of these came from Drennan, six from Dylin, and two came from dialogues with both students.

At only about twenty minutes into the 1st session, while Drennan and I were brainstorming possible field trip ideas, I stumbled onto this topic that Drennan became very excited about. This was the start of a trend that continued throughout the semester, right up to the last class.

Me:	What kind of field trips would you wanna do?
Drennan:	That's what I was just thinking about; how would they pertain to this kind of class?
Me:	Well let's see. With motion and force, it would be so cool to do like a ballistics something. I don't know where we would go for that, but…
Drennan:	Ballistics! How, what we would blow something up or what?
Me:	Kinda like! Like how fast something's moving and how big of an impact it has; would be force, motion, momentum…

Drennan was not about to give up on the possibility of exploding something for academic purposes. During the 2nd session he made sure to mention explosions as possible field trip topics when we were addressing this part of the syllabus with Dylin as well.

Me:	The field trips will be doing things that we can't do in class, like going and…
[Drennan:	Blowing stuff up?
Me:	…blowing stuff up, shooting things, going on rides, and explaining it in terms of physics.

By the second class, Dylin was starting to talk about explosions too.

Me:	So what's an experiment? …What was experimenting?
Dylin:	When you prove or disprove your hypothesis? Whatever your hypothesis is, blowin' up stuff, I don't know, whatever you're doing.

After two more references to explosions in just this session alone, I started to notice that something was going on, and I commented on it. Making note of the trend acknowledged explosions' seeming importance in the shared classroom space, thus making it a part of the classroom culture.

Drennan:	All this stuff I'm gonna be learning I'm actually gonna try it on my own, you know? 'Cause, I mean, it's a big desert out there, and no one's gonna bother me if I blow up something or, you know.
Me:	[laughs] What is this obsessions with blowing things up?
Drennan:	I don't know!
Me:	You boys. 'Cause it's fun and awesome?
Drennan:	Yeah, it is fun! I don't know why, it just is.

From this point on, the notion of explosions continued popping up in the different dialogues. It showed up in the 4th class when Dylin was trying to make up a scenario for asking a question about constant velocity and Newton's 1st law of motion, and in the 7th session's discussion of energy and power with Drennan. It came up twice in the 11th session with Dylin where we were talking about gravity: once in talking about escape velocity, and then again as we explored the trajectories of ballistic missiles. I was actually the one who brought it into a conversation with Drennan in the 12th session, when in response to his question about the energy used by a person in their whole life, I looked online and found a comparison between a person's energy and the energy released by an atom bomb. Drennan brought in another example in the 12th session when I asked him about pressure in car tires.

Me:	Right so how many pounds of pressure per square inch [is] how much pressure's being pushed against it for every square inch. It's pretty high in tires, otherwise what would happen?
Drennan:	It explodes. You put in air and forget about it and then boom.

Although the students just loved the idea of explosions, they were not merely superfluous additions to the conversation; they also served the function of exploring physical concepts. In another example from the 12th class (previously described in the section on Momentum), we talked about the conservation of momentum relative to a car crash. As far as Drennan was concerned, this was a perfect opportunity for an explosion, but it was an explosion with a purpose: he could use it to explore and deepen his understanding of energy and conservation of momentum. Drennan remembered and was able to communicate this explanation to Dylin during the final exam (14th session), and Dylin was then able to apply this explanation later when he was demonstrating his class project on ballistics.

While the use of explosions to develop and demonstrate conceptual understanding was worthwhile, this recurring topic was also used for another purpose: it was fun, and it was funny. Explosions became a running joke in our class, doing what inside jokes tend to do: establish an "insider" group to whom they are funny. In other words, they contributed to establishing a class identity. The following dialogue from the 14th session, which pertained to Part 1N of the final exam, shed light on the role of explosions for this purpose. Question 1N asked students to come up with real-world applications of the concepts that came into play with the marble scenario; what follows were the students' responses.

Drennan:	A car would involve a lot of these forces.
Me:	Okay, so how does it compare? What's an analogous situation?
Drennan:	I mean, the exact same thing. It could be just [a] car instead of a marble. Let's say a diesel just parked at an intersection and a car's coming down an off-ramp and it has no brakes. And when you're going on the highway, you know, you've got to go fast, go with the flow of traffic, so it's cruising down the off-ramp and he can't stop. He can't do anything but just keep going and bam into that diesel that's parked there, waiting its turn. And all the energy's going to spread out on the diesel. It depends on what part of the diesel it's going to hit, if the diesel will bend some and I'm sure the car will be totaled and chunks flying everywhere. And I'm pretty sure that all that heat energy will also cause the engine to explode.
Me:	I knew you were going to say that.
Drennan:	That could be like…chemical energy. And so, I mean, even inertia: the driver's going to try to keep going and so is the engine of the car. It's going to try to slam into the diesel. And the diesel guy, the driver, he's going to feel it too because he's going fly to the side. And you're going to hear a loud bang, crunch. Well, the explosion you'll probably see.
Me:	[laughs] All right, good. Dylin?
Dylin:	That's exactly what I was going to say. [they laugh]

Me:	How about something that's got potential energy because of how high it is…and it's colliding with something at the bottom.
Dylin:	How about an air crash.
Me:	Oh, good. You guys like things to crash.
Drennan:	And even like a falling star, or collision of two planets. Like if a planet's…or let's say if the Moon crashed into the Earth.
Dylin:	How about something simple like a hammer falling from the table and smashing my toe.
Me:	[I laugh] How about a skier skiing down a mountain and not getting hurt. How about that?
Dylin:	Hey, we're guys.
Me:	I know, I know.

Explosions were a connection the students brought into the classroom because, as Dylin said, "we're guys", and explosions were particularly interesting to their demographic. The opportunities to imagine and discuss explosions were a way for the students to engage with physics and to use physics to explain a real-world phenomenon (rare though this phenomenon may be); they were also opportunities for us to define ourselves as a group of people who, for one, all think it's funny to keep talking about explosions.

Atlatl

One of the activities we did as a class, under the guidance of our cultural advisor, Jiles, was to build and learn to use an ancient traditional weapon called the atlatl – a device that accelerates a dart to high speeds using the power of the thrower's arm. The atlatl served as both a cultural application of physics, and a context for learning physical concepts. The class discussed the mechanics of its use, which allowed the students to see the physics in action. In addition, as an example of human technology imbedded within a cultural way of life, it allowed the students, particularly Drennan, to look at physics across time and across the generations of their ancestors. The six dialogues about the atlatl identified as opportunities for meaning making occurred in the second half of the semester as well as in Drennan's journaling homework. Three of these dialogues were with Drennan, two were with Dylin, and one was with both students.

The atlatl was chosen for the course because it was a tool that had been used in the past almost universally across the globe, and according to Jiles had been used by the O'odham's ancestors; it also served as a hands-on application of Newton's laws of motion and was something the students could build themselves. Thus, it appealed to the students on three fronts: cultural application, physics application, and hands-on engagement.

In the beginning, the students struggled to explain the mechanism of the atlatl using physical concepts; as they continued using it and exploring its motion, they tentatively began to use physics to describe what they experienced. Over time, they became better at both using the atlatl, and at applying physics to explain its power. The brief excerpt below, from one of our early exchanges about the atlatl's mechanics from the 8th session, is just one of many examples that demonstrates how engaged the students were in trying to figure out what makes the atlatl work. We were trying to figure out what makes using an atlatl superior to hand-throwing a spear, and I mentioned the fact that, compared to just throwing a spear, you move your arm a lot less when using the atlatl. Dylin asked a follow-up question to delve into the reasoning behind my comment, and Drennan posed a scenario that extended on it.

Me:	I think if we drew a picture of your hand throwing it as far as it will go, then you have this much of an arc, whereas if you have the atlatl in your hand then it's going back even further and it's gonna extend even further out there, so it's got a much bigger arc.
Dylin:	What does it matter how big it is?
Me:	It matters because then you're applying that same amount of force over a greater distance, and that gives it, that means it's doing more work on the arrow, which means it's giving it more energy.
Drennan:	So wouldn't a guy with a long arm have an advantage to it?
Me:	It seems that way. If that's the mechanism that's making it work, then yeah.

Dylin and I had an extended Socratic dialogue in the 11th session that went much deeper into the many physical concepts of which the atlatl makes use. During this discussion, Dylin elaborated on the phenomenon described above. He compared moving one's whole arm to throw a spear to moving just one's hand to "flick" an atlatl.

> …it just seems like you lose a whole lot of your energy because you're using it actually to do the arm, to go like this [move arm from shoulder to spear-throwing position]. Then, where you just go like that [flick wrist to release dart from atlatl], you're not wasting all

that energy and the motion; you're transferring more of it into the object than you are when you're doing this…this is taking a lot of that energy.

Dylin's explanation became more sophisticated, now including the notion of energy transference. He was also able to accurately describe, through a Socratic dialogue, the roles that inertia, potential energy, and Newton's 3rd law play in accelerating the dart, which is intentionally flexible to give it more kinetic energy, as described below.

Me:	If the dart is flexible…what's gonna happen when you push it with the atlatl right here? …What's that thing that masses do, what's Newton's first law?
Dylin:	Uh…so that's why it bends.
Me:	What's Newton's 1st law before I let you get away with that?
Dylin:	[laughs] Things in motion tend to stay in motion?
Me:	Yeah. Ok. Things that are not in motion…
Dylin:	Stay *not* in motion.
Me:	Tends to stay at rest, resists the motion, so it wants to stay still. This [the mass] wants to stay still and this [the end of the dart] is being pushed, what's it gonna do?
Dylin:	It's gonna bend.
Me:	So what happens? So now you have a certain amount of potential energy in this, based on…how much it bent. What's gonna happen to that potential energy; where does it go?
Dylin:	It goes to pushing the arrow out the atlatl.

Another purpose the atlatl served was providing the students with a context for developing their own investigable scientific questions. Drennan was posing questions about the atlatl almost as soon as the atlatl lab began. While his initial questions were more to satisfy his curiosity than for the sake of scientific inquiry, he used them to springboard to potential investigations.

> Does it [the atlatl] have to be a specific length or could you just make it for, like, a smaller one for hunting rabbits and a long one for…Maybe we could do that, make different weights, ones that are little ones, big ones; little targets.

While we did not have time to pursue Drennan's questions, we did attempt to study whether an atlatl-thrown dart would outdistance a hand-thrown dart. It was mainly Dylin who was involved in performing the experiment and analyzing the data, which, because we lacked skill in either of these activities, turned out to be quite messy. However, the lack of clear results from the experiment was an opportunity for Dylin to reflect on the process and examine the confounding variables that interfered with our data. In the end, he came up with some recommendations for future classes.

> If you teach this class again you could…start right from the beginning making the arrows and the atlatl and practice every class. 'Cause it's pretty fun; if you could really do it…you could really get some good data and figure it out.

As useful as the atlatl was for teaching science, it was just as powerful as an opportunity for students to gain exposure to just a bit of the scientific knowledge developed by their ancient ancestors. Drennan seemed to be the one who most benefited from the cultural physics application, expressing on several occasions his appreciation for his ancestors' ingenuity. The atlatl came up, for instance, in his dialogue from the 12th class about energy, life, and evolution.

Drennan:	Doesn't that make you kind of curious?
Me:	About?
Drennan:	Humans. I mean we kind of seem to be one of those animals that doesn't really belong….We just pretty much adapt to everywhere. It's like we were designed that way, so…not to sound religious or nothing – divine inspiration.
Me:	I don't know, I mean a part of why we can adapt so easy is because we have technology, which…we could not only learn but record what we learned so the next generation could learn it as well. So we can simulate knowledge in ways other species can't.
Drennan:	Like the atlatl.

He made similar remarks in his journal and his interview with me at the end of the semester. In his journal writing, he talked about the physics connection between atlatls and projectile motion, inertia and gravity, but he also made a cultural connection by tying the atlatl to its function for the people, parallel with the technology of today.

> Projectile motion is used in daily routine when people practice their pitches in basketball or football. It's all affected by gravity or it would continue on its trajectory until another object acts upon it. Our atlatls used projectile motion also but we weren't good enough to push it to its full potential. It was truly a weapon of distance. I suppose [it] was our rifle of its time.
>
> Did they have different sizes or should I say calibers for different animals?

When asked during his interview how his impression of culture had changed since taking the class, Drennan responded that the atlatl was one of the things that changed his perspective. He expressed an appreciation for his cultural scientific heritage, and that this experience had triggered a curiosity about what other scientific knowledge his forebears possessed.

> I never really, um, like I said before, the whole atlatl thing, like I wonder what else! I wonder what else, because it seems to be a universal truth, you know, the atlatl, and everybody on every continent has used it, you know.

Drennan also recognized that such knowledge had the potential to be relevant today as well, and that knowing how to use an atlatl could come in handy in certain circumstances. In the midst of a conversation involving both students (8^{th} class) about a possible post-apocalyptic future, Drennan mentioned,

> I think we should learn this stuff also because what if something happens, all this is gone; you need to learn those skills…Or if you're out in the middle of nowhere, just make one of these, with your shoestring.

The students were able to apply concepts they were learning about to their experiences, shared by the class as a collective, with building and using atlatls. The atlatl lab was also an opportunity for the students to pose scientific questions, collect data, and reflect on the results. For Dylin, the atlatl experience's key value was in providing a context for him to apply his learning about mechanics. Drennan also found the atlatl useful for this purpose, but for him the atlatl's major value was in connecting him with his scientific heritage. Both students made reference to the fact that we were not able to learn all that we could from the atlatl because we did not give ourselves to become proficient in it. As Dylin had mentioned, centering the curriculum around the atlatl lab could be a worthwhile revision that would allow students to go in depth with it; grounding the whole course in the context of the atlatl would provide more opportunities for students to investigate questions, apply physics, and connect to the knowledge of their ancestors.

Heat

Heat is a topic that fulfilled a similar role to the atlatl, in that there were content-based understandings as well as cultural and philosophical understandings being developed through the dialogues. There was basic content knowledge – the types of heat transfer, conductors and insulators, basic versions of the laws of thermodynamics – alongside a traditional O'odham story, the role of ceremonies for equilibrium, and a philosophical interpretation of entropy.

The discussions about heat took place almost entirely in the 13th class session with Dylin. Nine dialogues were identified for this topic: seven of them with Dylin, one with Drennan, and one with both students. These dialogues related both to developing conceptual understandings of the physical concepts of heat and the laws of thermodynamics, as well as to exploring cultural scientific knowledge within the O'odham tradition.

In our after-semester interview, I asked Drennan if he had suggestions for other ways we could have incorporated culture into a physics class. As someone who grew up in the desert and knew it well, Drennan had a wealth of ideas; maybe someday, he will be the one teaching this class. One of his recommendations was for the class to apply physics to investigating what the O'odham people know about the desert.

We coulda measured how people use the desert; like how other tribes, they use the sweat lodge, but us here in the desert, the desert's our sweat lodge, you know?...We could have focused more on the lifestyles…Out here there's a certain kind of lifestyle that you live…and it's actually pretty harsh…out here, and you have to know a certain way to do things.

Drennan's ideas focused on using Western science to explore and validate cultural traditions. His vision for the course was highly grounded in the place and the people of the college, and the science that underlies all that the people do in this place, including the ways that they thrive in a land with such extreme high temperatures. We explored the topic of heat in a class in which our cultural advisor, Jiles, presented an O'odham story relating to the weather. Dylin was the only student in class for this session, and he used the story as a resource for doing exactly what Drennan suggested – looking at evidence of the people's physical understandings.

Prior to Jiles' story, Dylin and I discussed the concepts of equilibrium, conduction, insulation, convection, and radiation through a Socratic dialogue that drew in connections relevant to Dylin. Using the inside of Dylin's car on a hot day, and the insulation in his house, we created a context for looking at heat and its associated components.

Me: So, if you have two things that are different temperatures, what's gonna happen to the heat?

Dylin:	It's gonna cool down? …And it's gonna heat something else up.
Me:	Ok, until what happens.
Dylin:	They balance out.
Me:	Exactly. Equilibrium…If you're in your car and you sit on the seat versus you touch the buckle of your seatbelt, which one feels hotter?
Dylin:	The buckle.
Me:	But, if they're in equilibrium, what must they be?
Dylin:	The same.
Me:	So what makes it seem hotter?
Dylin:	The metal part. Insulation?
Me:	Insulation versus conduction…What's insulation do? ...If you put insulation in your house, what happens, what does it do for your house?
Dylin:	It keeps it the same temperature, whether it's hotter or colder.
Me:	So it keeps heat from transferring either from outside in or inside to out. Same thing, if you didn't have it, what would happen?
Dylin:	High energy bill. [we laugh]
Me:	What would your house do compared to the outside world?
Dylin:	It would do whatever it does; if it's hot outside it'll be hot inside.
Me:	Exactly. It would be in equilibrium with that system.…Then, conversely, what would conduction do, what would a conductor do?
Dylin:	Transfer?
Me:	Right. It, so it permits heat transfer. How about your buckle?

Dylin: Insulator…could be the opposite, but I think the reason why it’s not hot is it’s letting the heat pass through it.

Me: When you’re in your car, which one’s hotter, you or the car? And it’s a really hot day.

Dylin: The car.

Me: Ok. So you’re the cool thing, it’s the hot thing. So what’s it gonna try to do to you?

Dylin: It’s gonna try to make me hot.

Me: Ok, it’s gonna try to transfer heat to you. So which one transfers the heat to you more effectively? The buckle or the seat.

Dylin: The buckle.

Me: So what kinda thing must it be?

Dylin: Conduction?

Me: Conductor.

Similar Socratic-style dialogues were used to lead Dylin to understanding convection (using the example of spaghetti cooking in a pot) and radiation (using such examples as Dylin heating up food in the microwave and listening to his favorite music on the radio). Following these discussions, Jiles told the O’odham story about the Sun and the balance of the elements; a synopsis of this story follows.

The Wind is banished from the O’odham world because he offended one of the people; he acquiesces but wants to take his friend the Rain with him. The consequences of the absence of Wind and Rain lead the community to want to find them and bring them back;

everything was out of balance. Coyote, Bear and Buzzard each go out to look for them and can't find them. Hummingbird finally finds Wind and Rain and tells them they're wanted back. They are reluctant to go back after they were treated so badly, but Hummingbird tells them the community realizes how important they are. Wind tells him the community has to show them they want them back with a ceremony of four days and four nights. The community agrees, and on the fourth morning of the ceremony, the people are sitting watching the horizon and they start to feel the breeze. The people rejoice and resume their planting and activities while the clouds come. The ceremony is still being performed, but only by a few people these days.

After Jiles' departure, Dylin reflected on the scientific knowledge possessed by the O'odham people and conveyed through stories such as this one.

I was thinking about these thing[s] and what they have to do with the story, the culture…They had to have some sort of knowledge of…the natural world, how it works, and becoming in tuned to it. Instead of how we do it now, where we destroy it, you know we adapt…Nature to us instead of us adapting to Nature.

Dylin identified several ways that the story and the physics validated each other. Focusing on the character of the Sun, Dylin recounted the knowledge communicated by the story – not only scientific knowledge but also cultural values:

The Sun is the father, grandfather, the place where it all starts. Which is true because without the Sun, we won't have life here. That's a fact, whether it was two thousand years ago, or twenty thousand years.

He mentioned as well how the story talked about the Sun giving off tremendous heat, relating back to our physics topic of thermodynamics. He also spoke of how the Wind pushed the Rain around, which matched up with the reality of rainstorms in Dylin's experience in the desert.

> I like the part where he was talking about how the Rain's deaf, dumb, blind and whatever, and the Wind is the one that leads him around, 'cause when you think about it, the wind does push the direction of where the rain comes down.

The story also showed evidence of an understanding of the connection between air pressure and weather, which is also related to thermodynamics: wind is a differential of pressure caused by different temperatures of air. Dylin and I discussed this relationship as it relates to the town of Sells where the college is located, presented in the following excerpt.

Me:	Say the pressure over Sells is low today. So we have a low pressure area, while the rest of the world is at some other pressure area; what's gonna happen to the air that's out here? …What does the air do to equalize the pressure? If you've got high pressure and you've got low pressure…What happens to the air outside?
Dylin:	It gets sucked in.
Me:	Yeah, it gets *pushed* into…the low pressure, to equalize it…It's gonna come rushing in, right, and it's gonna bring with it all its moisture that it had. So what's gonna probably happen in Sells?
Dylin:	It's gonna rain.

Me:	Right, it’s gonna be rainy and cloudy.
Dylin:	Yay!
Me:	When the pressure is high…?
Dylin:	Then, all the moisture’s gonna go somewhere else, to the lower pressure.
Me:	So what’s gonna, what are we gonna have in Sells?
Dylin:	It’s gonna be hot and dry.
Me:	So we’re talking about wind leading rain; it’s because the wind brings the rain with it, right, and when you start [noticing] the wind...Because that rain’s bringing in moisture with it, hopefully. So there is that knowledge imbedded in the story, that the wind carries the rain. The Wind drags Rain around with it.

Finally, Dylin was asked to identify where in the story he saw conduction, convection, and radiation, integrating the physical and cultural concepts.

Me:	What happened when Wind and Rain took off?
Dylin:	Everything got dry and hot; plants started dying out in the desert.
Me:	Why does the wind and rain keep things from being hot, dry, and dying?
Dylin:	It naturally cools it down. [When it’s windy and] it’s hot, even though it’s still blowing probably pretty decently-hot air, it’s still gonna cool you down a little bit.
Me:	What kind of transfer of heat is that?
Dylin:	Convection.
Me:	Which thing, which thing in the story uses radiation?

Dylin:	The Sun.
Me:	What uses conduction?
Dylin:	The rain?…When the raindrops hit something, the heat gets transferred to the rain. So that would take some of that heat away.

While the bulk of the dialogue around heat involved instructor-led Socratic questioning, there were opportunities for Dylin to introduce topics of interest to him, and as it happened, these interjections also allowed us to tie back to the thermodynamics topics of the day. In the following excerpt, Dylin was lamenting the role that modern humans have in the environment, and the discussion that followed from his thinking led us to the notion of entropy and the third law of thermodynamics, which in layman's terms refers to the fact that the order in a system can only be increased by adding energy.

Dylin:	When Jiles was talking, I wrote down here, I was just thinking, how Nature is always one. Even if something's killing something, it's a purpose; it's not trying to destroy Nature, it's just part of the whole cycle. And I was thinking, we're pretty much the only things on Earth that doesn't do that. So can we really say we're part of Nature if we don't do that…I look at it as, humans aren't here, the Earth is better. And if you look at anything else on Earth, like you say, "well if there's no sharks," you can't say the Earth is better. If you say, "oh there's no birds, there's no spiders, there's no mosquitos," any other insect, species of animal, if you say they're not there, it doesn't make the Earth better. The only thing you could say that taking if off the Earth would make it better is humans.

Me:	But if we get out of control, my suspicion, and this again is another of my wild theories, is that Nature will take care of it. It will either knock that part of the population out, make us start over, or we take off, we leave but leave whoever's left over to do what they're gonna do. But that somehow, if things get out of control, Nature will take over. Nature will step in.
Dylin:	But what if we're taking that ability away from Nature? With the antidotes, with all this stuff, you know.
Me:	We can't prepare for everything. The more we try to do that, the less we're able to do it; that's entropy, and that's the [third] law of thermodynamics! [laughs] That disorder in the Universe is increasing. And the more you try to control it, the more energy it takes to try to control it. And the more energy it takes, the less you're able to put in energy….There's no way you can control absolutely everything. There's not enough energy in the world. That's a total extrapolation of the third law, but I swear it's in there somewhere. [we laugh]

In the following excerpt, Dylin tied his previous thought and the role of ceremonies to both the interpretation of entropy that I presented above as well as to the concept of equilibrium, another important idea in thermodynamics that we discussed earlier. He also made reference to our lab activity for this class session, which was building a solar oven out of a recycled pizza box and using it to melt chocolate for s'mores.

Dylin:	I think there's a lot of…I don't wanna say reality, in ceremonies…Usually what they say they're gonna do, whatever ceremony it might be, it does it.

And I think that goes back to, like you say, the equilibrium with Nature…We don't really celebrate the Earth, you know; it rains, people are like, "ah crappy, it's rain." You know? I've never once ever said, "It sucks because it's raining right now." Because it's great, because I know what rain is, especially in the desert: it's life, it's beautiful, it's great. Even if it is flooding, even if it causes some damage, it's always a wonderful thing. But we as a culture, society, don't do that anymore. It's unimportant. It's a cycle, it's not something to be celebrated or praised or even asked for.

Me: So it's like these ceremonies are a way of re-establishing what place we have in this environment, this ecosystem…A lot of the time we no longer recognize where we stand in relation to all these things. We no longer see ourselves as a part of everything else. A lot of people still do, they still recognize it, they still celebrate that, and they re-establish these things over and over. There are societies who do that solely to keep the whole rest of the world in balance.

Dylin: Which is exactly what I was saying…Like you were saying, eventually Nature will correct itself and create a plague or something that causes us to wipe ourself out, or the majority. And it's the people who still believe, I don't wanna say ancient things, but wanna recycle, love the Earth, wanna do those typa things, that keep everyone else…or keep Nature from taking back stuff…Who cook s'mores…

Me: [laughs] …In pizza boxes!

Through the explorations of the topic of heat and the laws of thermodynamics, Dylin was able to develop content knowledge contextualized within his experiences from living in the desert. He was also able to draw parallels between this content knowledge and understandings about Nature inherent in the stories told in his cultural tradition. The physics concepts were brought in to interpret the story, and the story was used as a context for learning the physics concepts.

Fields

The concept of fields was emphasized in this course specifically because I thought that fields, and in particular the notion of action across a distance, would resonate with the students in a spiritual sense; it was intended to be a potential cultural connection. Fields were discussed in only three meaning-making dialogues: once in the 11th class session with Dylin, once in the 14th class with Drennan, and again in the 14th session with both students. However, these dialogues were significant because of the fact that they did not go at all as I had expected.

Dylin connected force across space (e.g. electromagnetic or gravitational) to the Force in Star Wars (11th session). That is, force fields actually connected with Dylin's personal interests rather than his cultural background. However, his understanding of the Force in a Star Wars sense provided a potentially useful context for force and their fields in a physical sense.

Me:	See I think this whole idea of a field is interesting stuff, and I thought you'd be interested in it too, but perhaps not. It's something that exerts a force

without having to touch. Like gravity…it's across *space*. It's across emptiness.

Dylin: It's Star Wars.

Me: [laughs] I guess.

Dylin: I mean, they call it the Force, when you can move things without touching it.

Me: Yup. That's right, that's what it is. I don't know if they would consider gravity "the force," but it is a force.

Dylin: The book I'm reading, they're going into a whole new area of the force….Like, "we've been doing it wrong; there is no light side, there is no dark side."

Me: Ah. There is no bipolarity.

Dylin made the connection between fields and the Force immediately, and from this point launched into a brief monologue about the characters having to completely reconceptualize it. In the end, he concluded, "Especially taking this class, [the series] sounds pretty accurate in physics." He extended this thought to talk about the realism of one of the plot threads.

Even the transmissions, like right now Leia and Han, they're going around the galaxy, trying to re-put up satellites…so they can transmit messages through the galaxy…It's realistic, like what would we do here if a phone tower went down [and] this whole area's blacked out. You can't call in or call out. So they go in and put up power so they know what's going on in this region of the galaxy…So they're going to these places not knowing what's going on trying to re-set up the communications.

Dylin's connection was a metaphor for fields, with the characters sending information about the Universe across a distance. This may not have been intentional, but it could have been built upon to develop a deeper understanding of the concept, and would have been an interesting area to examine for parallels. My hope would be that he pursued the parallels himself the next time he read his book.

In the 14th session, Drennan described a field as "an area bubbled by energy to Earth", which he explained was referring to the shape of fields (they are typically drawn as a sphere, or "bubble", around the source). In response to Question 5 on the final ("How would you explain what a field is? How does it relate to gravity?"), he reported:

> When I said how does it relate to gravity, I wrote the Earth is surrounded by a gravity field…and if anything comes too close or in contact with the field, you get pulled towards the planet.

Drennan's responses demonstrated his understanding of fields as containing energy and being the purview of a force, in this case the gravitational force. He reiterated this understanding with another example when asked what other fields there are: "I guess heat; like a fire has a certain area. If you get too close you're going to burn." In this case, he made a comparison between a field and the area around a fire where you can feel the heat.

The students' conceptions of fields were more inclusive than mine; in the course of the following discussion (14th class), I repeatedly constrained the definition of fields to force fields, i.e. classical fields that exert a force, such as gravity, electrostatics and magnetism. The students argued that other phenomena should be considered to be fields as well, such as Drennan's example of the heat of a fire. This led the students to consider other possibilities. The excerpt below shows a negotiation among the class about what qualifies as a field.

Dylin:	It works like telekinesis…Like in Star Wars.
Me:	Can you exert a force with your mind?
Drennan:	Yeah. I mean you're sending electric charge through your muscles to move physically…is that the same thing? Turn something mental into physical?…Couldn't that be a field?
Me:	Can you create a field that can exert a force across the distance? That's what a field is…It allows you to exert a force across a distance – empty space. Like you can feel the force across empty space if you have gravity.
Drennan:	Everybody creates some heat with their body, right? Would you be able to focus enough to create enough heat to come out of your hand, to disturb the air, to have a physical reaction to give something?
Dylin:	There was a study on Buddhists monks where…they had to sit in a cave for 24 hours…and meditate, and it's like zero degrees or something. So [the researchers] that went with them, they took their infrared camera and all that and put temperature readings all around them, and…they said around him, within a certain area, the temperature was 98° consistently…So a field, I guess you could say, where he was in that kept his temperature normal…So, would that count as a field, he's using that heat…to create this energy field around him so he's not getting cold?

Me:	Remember, a field is a force. A force field, you should recognize that from your Star Wars. [all laugh] So heat doesn't really exert a force, but it kind of – I can see where it's similar; you can sense the energy around, in a certain area, that decreases as you get further and further away…But it's not exerting a force…There's no heat field that I've ever heard of. And I don't know why not…
Drennan:	What would that be then? …Why isn't it considered a field?
Me:	Because it doesn't exert a force.
Drennan:	What if…the heat was constant in some area and you put a piece of ice and it started to melt there. Like it was the same temperature as the ice around it, and it was solidified when you just moved it away from the field, but if you moved it closer to him and it started to melt, wouldn't it be causing a boundary to the field?

The first application of fields, which Dylin came up with through his connection to Star Wars, was telekinesis, a supernatural phenomenon outside the scope of physics. When asked if we can exert a force with our minds, Drennan answered clearly in the affirmative: "you're sending electric charge through your muscles to move [them] physically." Drennan's words on this topic suggest a transformation and transference of energy: "mentally causing that physical…" Drennan was using physical explanations to account for a supernatural phenomenon. The students' persistence persuaded me to reconsider my limited definition, providing space for Dylin to suggest a scenario, and Drennan to build upon it, to underscore the students' argument.

What is interesting about the field discussions is that I as the instructor had originally thought that fields would appeal to students in a spiritual way: phenomena that reveal that discrete entities in the Universe are indeed connected and can influence each other across the fabric of space-time. While the students were interested in fields, my expectations for how they would connect with them were way off-base. It is possible that the O'odham philosophy of interconnectedness was the foundation for how readily the students understood the concept of fields, but the connections they made were certainly not readily identifiable as "O'odham connections". Dylin related fields to Star Wars; Drennan, with his mentions of "boundaries", seemed to be thinking of shields for scifi spacecraft; and both latched onto the potential for *humans* to act over a distance via mental powers. The students pushed the boundaries of physics to incorporate other natural and supernatural phenomena into the territory of fields.

Newton's Laws of Motion

Together, Newton's three laws of motions were discussed across the duration of the semester, starting in the fourth class and through to the end of the course. The most frequently discussed of the three laws was inertia (Newton's first law), for which dialogues were identified in the 4th through 7th, 11th and 12th sessions as well as Drennan's journaling homework, for a total of eight dialogues. Five of these were with Dylin and the other three were with Drennan. Newton's second law of motion, which states that the acceleration of an object is proportional to the force on it and inversely proportional to its mass (in other words, a heavier object requires a greater force in order to change its motion, as compared to a less massive object), was discussed in four dialogues from the 5th, 6th, 8th, and 14th sessions. Three of these dialogues were with Dylin and one with Drennan. Each of these dialogues pertained to examples and questions to help elucidate the concepts for the students, though the dialogues of special interest are those involving examples and interpretations put forth by the students themselves.

Newton's third law of motion, which states that forces come in equal and opposite pairs, was only addressed in two class sessions, the 9th and 10th, with three identified dialogues: one with Drennan, one with Dylin, and one with both students. In the dialogues with individual students, each worked to come up with his own personal understanding of the concept. In the dialogue with both students, we co-constructed a multi-faceted interpretation of the third law by drawing in connections to distinctly non-physical topics, a process which resulted in a dialogue unique to the interests and personalities of the members of the class.

<u>Inertia</u>

Each student drew upon one specific example apiece to help him understand Newton's first law of motion. Drennan's connection to inertia was in his experiences being a passenger in a car. We put inertia into this context in the 7th class session, in which we discussed how we can "feel" our inertia when in an accelerating car. Following my asking Drennan about his personal experiences as a passenger in a car to contextualize the idea of feeling acceleration in your body, he described inertia in his own words.

Me:	If you're in the passenger seat with your eyes closed, how do you know the car is accelerating? How can you feel in your body that the car sped up?
Drennan:	It gets pushed back in the seat.
Me:	What happens when the car slows down? [Drennan mimes] You get pushed forward right? What happens when the car changes direction?
Drennan:	It goes the opposite way depending on which direction you're going. If it goes right, you go left.
Me:	Exactly. So whatever the car's doing, you do the opposite, at first…What is the physics concept that makes your body do that?
Drennan:	Would it be the inertia?
Me:	How would you describe it to somebody when you're talking about inertia, what it means to have inertia?
Drennan:	Well inertia…if I described it to someone, is your body still going in the direction that you were going in first.

Drennan recapitulated this context in the 12th class; when asked "what does inertia refer to?" He replied, "Like a person in the car when they stop and they're still trying to go forward, it's that energy of wanting to continue in that direction that it was already in." While his description provided evidence that he understood this concept, it was in his journaling homework, presented here as Drennan typed it, that showed that he truly connected with the example to which he kept coming back.

We all have taken a drive with a friend who decides to take you on a death cruise. Hitting turns at high speeds is an adrenalin pumping experience. We are jarred around in out seats but luckily this is why seat belts were invented. The forces acting on us are never thought of until we get into an accident. Inertia is the last force felt until the seat belt stops us from going through the windshield. Our vehicle is decelerating but we are not. We continue on our trajectory at the accelerated speed prior to deceleration if not for the belt's stopping force acting upon you another force of resistance will stop you instantly at its origin which most likely would be from the dash board or windshield…

Although Drennan mistakenly referred to inertia as a force, he was correct that the force of the seatbelt, or the windshield, is what we feel as it counteracts our inertia. He was able to express his understanding of inertia eloquently by tying it to a highly-detailed description of an event that, it appears, he had actually lived through.

Dylin took a different approach to gaining awareness of inertia, taking it into the context of space travel and exploring its implications in this setting. In the 4th class, he described Newton's first law of motion in his own words through a question he asked.

Space, vacuum, something moves…it's not gonna accelerate…Since there's really no air, is it gonna maintain that speed and direction forever until it either hits something else or whatever?

After learning more about inertia, he returned to this question, describing the scenario of a spacecraft again but with more physics. Although he did not use the word "inertia", he included references to "keep[ing] momentum", to the interactions with other forces (i.e. gravity) or lack thereof, and to "maintain[ing] that speed" at which it left the Earth's atmosphere.

If you didn't need to stop, or you had something pointed in a certain direction, like a mission to Mars; don't need much fuel to get there. If it's unmanned, you've got the right coordinates, you shoot it out; basically you just keep that momentum, because theoretically in space, no gravity…there's really not anything unless you hit something…you don't need much fuel once you're out of the atmosphere to reach your destination. So if…you're out of [the atmosphere], you're in space at 10,000 miles an hour, you should pretty much maintain that speed throughout your travel.

Dylin correctly identified the outcome of inertia in space, being that, in the absence of the Earth's gravity and atmosphere, a rocket's inertia would take it all the way to its destination. Like Drennan, he had found a context for inertia that helped him to understand its influence on moving objects, though the two students' contexts were quite different.

Newton's Second Law

Newton's second law is a fairly intuitive one, and not a topic we discussed at great length, though as with the first law each student found a context that helped him to examine it. Dylin's was again space travel, but specifically from the perspective of characters from the Star Wars novels. Although, as with inertia, he did not refer to Newton's laws in words, his scenario (6th class) employed the components of this concept as he explained why a gravity assist maneuver would allow a smaller ship to accelerate more quickly than a larger ship.

Han Solo, he'll do looping maneuvers…They have to get to a certain speed to go into hyperspace, so what he does is he gets [to] the planets and he'll circle around, and it takes

> a lot longer for the big ship to do it, and by the time he comes back around, he'll have enough speed to jump into hyperspace…If he goes around…when he gets there, he can shoot out…they can shoot out too, but they don't accelerate as much.

In theory, what he described involved the same force being applied to both ships and thus accelerating the less massive ship more, although in reality the forces would be proportional and the accelerations the same (assuming all other variables are equal). To Dylin, what the books portrayed made sense as an application of Newton's second law.

Drennan's example came from the final (14th class), Question 1 Part I, in which he was asked to identify an application for acceleration. Drennan drew in Newton's second law by explaining how different forces influence the acceleration of billiard balls.

> Billiards, same thing…let's say you're trying to get the eight ball into the corner pocket and…you know you're going to need to move it that certain distance…And if you just apply a small amount of force to the eight ball, it won't really cause…the ball to move too far because you don't apply as much force to it…and there won't be much acceleration. But if you apply a harder force, then it will cause the ball to move further and further and get into the corner pocket.

Drennan's real-life application of the concept tied to the marble experiment from the final in which the mass of the moving object (the cup or the billiard ball) is held constant and only the force is under investigation. His example demonstrated how acceleration is proportional to force, in contrast to Dylin's which showed how acceleration is proportional to mass. These two relationships are two sides of the same coin, and reveal that the students were able to apply the physics they learned in imagined but realistic settings.

Newton's third Law

Newton's third law is commonly recognized as the least intuitive of the three laws of motion, though it is the one that is more widely known by the general population. The students competently described the interaction of forces from a physical perspective when asked to do so as part of a lesson on mechanics. However, they took the discussion to another level in a free-form dialogue in the 10th class session that created several opportunities for incorporating metaphors for the 3rd law.

Drennan illustrated on the board the forces that propel an unsecured, inflated balloon (9th class); when asked "what makes it go?" he responded, "the air's pushing against the other air". In his mind (as portrayed by a diagram he drew on the board), the escaping air was pushing against the air outside the balloon, and the air outside was pushing on the balloon; this is not quite accurate, as the air escaping is what pushes back on the balloon, but it did rely on Newton's third law.

Dylin explained the third law well also, though he chose to do so in abstract terms instead of applied to a real-world situation. Dylin's explanation, which was a response on his oral midterm exam (10th class), encapsulated Newton's second law as well.

> There's two parts; [objects] can…attract each other, or they can push away each other. So if somebody has this amount of force, it's pushing the other thing with that same amount of force, but they're going opposite ways. This thing's bigger, it's gonna travel less; this thing's smaller, it'll probably go further 'cause it's using the same amount of force.

Dylin's explanation became a reference point for the dialogue to come. During this class session, Drennan and I reviewed concepts from previous sessions while Dylin worked on building a vehicle powered by Newton's third law for his midterm engineering project. As was typical for our class, we explored physical concepts through an interactive lecture, which left ample space for dialogues to arise. The conversation that sprang from these activities came about as students spontaneously connected what they were doing with other things they knew about. Dylin's vehicle design evoked a particular weapon in his mind, which led to a discussion of recoil, also an outcome of Newton's third law. Thinking about weapons and warfare led Dylin to think about conflict, stating "it seems like all of our major technical advances are due to war." Ruminations on this topic led us to the following (much abridged) conversation.

Drennan:	What we know of life seems to be competitive, at far as we know it. And it makes you wonder, how else would life evolve somewhere else? If we're that competitive…would [life]…stay the same, 'cause it didn't have to fight any other [creatures] off or things like that, or how else would it evolve? There's gotta be other ways to evolve than just conflict.
Dylin:	That's the only thing that drives humanity, is conflict. I don't think…it's like the Matrix, I mean it's a movie and everything, but how they were saying that 'we tried to put humans in a surreal [serene] happy environment' and the humans didn't attach to it. They had to have that conflict; they had to have the wars, the crime, the violence, all that, because that's what drives our society. And I think that's a fact, it's wired into our brains.

Me:	That's what [Drennan was] saying though, the conflict is what creates evolution. We evolve to be better suited to adapt to anything that comes up.
Drennan:	But what if there was no conflict, how…would something be able to evolve?
Me:	No conflicts like things are just perfectly the same all the time?
Drennan:	Like, would it evolve there, yeah.
Me:	There would be no reason to, unless it was an accident. I mean, there's no evolution.
Dylin:	The reason why the natural habitat is working [with] the conflict in there is, it's symbiotic. It's all relative. There's still predators, there's still prey, there's still, you know, even the trees fighting for soil and water and nutrients, but that's the natural balance…If you take away all the predators, and everything's nice and happy, then the prey get too many and they eat all the trees and then all of a sudden there's no food and then all of a sudden everything dies. So in order to have that type of symbiotic thing you have to have the conflict, you *have* to have conflict.
Me:	It's not even just about conflict, you could look at it just as forces in balance…If there's one thing going one way, there has to be something going the other way.
Dylin:	Newton's law.
Me:	Yeah, Newton's third law again, only in a different context altogether. But …it's much more than two-dimensional; it's multi-dimensional.

The connection between conflict, evolution, symbiosis and Newton's third law, which arose organically from this admittedly off-topic conversation but which served as a potent metaphor for reinterpreting it, opened the door to consider other kinds of balance in the world and expand the metaphor further. In the next excerpt, the students considered the need for a balance between conflict and peace in order to have a paradise that is, in fact, pleasing to all its inhabitants.

Dylin:	So how would heaven…work? …How could you know you're happy if that's all there is? Isn't that just a state of being? I can't say that I'm happy and joyful when that's all there is. There has to be an alternative, to say, either I'm mad or I'm happy but now I'm happy so everything's great, but if you're just happy then that's just a state of being.
Drennan:	What would [animals] be doing? Would they be feeding off us; would there still be predators we'd have to worry about there?
Me:	Have you ever seen that Calvin and Hobbes, [that said] heaven is supposed to be a place where there's no competition, there's no fighting, there's no killing [but] if there's no killing in heaven, then tigers wouldn't be happy…It was a joke; if there's no killing in heaven, if there's no chasing after smaller things, then tigers wouldn't be in heaven, because that's not heaven for tigers. So yeah, it's a very simplistic picture [heaven as a place without conflict].
Drennan:	But you don't believe in a place that's just totally positive, and then there's a place that's totally negative? Because wouldn't they even themselves out, in the harmony of the Universe?

Dylin:	My heaven is…sports bar, the people I like care about, that's heaven for me. Maybe [it] wouldn't be heaven for someone else – "hey, there's no…" whatever…And people go to hell because they are violent. They're all, that's what they have in their mind all the time…so they go to their place where, that's what's for them, there's always violence, there's always chaos, because that's what they've created for themselves.
Me:	But that to me sounds like life. What you were describing, that's kind of the way that we live it now….If it didn't have those bad things, you wouldn't have that Broncos bar to go to and enjoy yourself later. If they [the violent people], if there weren't people who loved them, they wouldn't be in the world in the first place, right? So I don't know, it seems like that's, the more we think about what perfect would be, the more it sounds like the way it is now.
Dylin:	Yeah. I agree. To…be happy, you have to have the other realms.

What began as a thought about conflict, particularly the role of conflict in progress (Dylin's contribution) and evolution (Drennan's contribution), ultimately became a tremendous resource for contextualizing the physics content. Personal interests drawn in over the course of the whole conversation (not all included in this excerpt) included the movie The Matrix and military weaponry from Dylin and animal intelligence from Drennan. The connections students made *were* the conversation – each connection brought in added to the development of conceptual understanding of forces in balance. Drennan's wondering about whether evolution can take place without conflict, and Dylin's wondering about the possibility of places without conflict, led to Dylin's realization that conflict is necessary for harmony in nature. After I reframed this idea as forces in balance, Dylin recognized that what he was describing was a conceptualization of Newton's third law within the context of the ecosystem. He went on to apply this concept to heaven and hell, which Drennan brough back to the notion of conflict; he also expanded the scope of harmony to posit that there would still be balance in the Universe as a whole if there were a place that was completely positive and a place that was completely negative. In contrast, Dylin went on to wonder whether heaven is personalized, an idea that localized harmony to the individual. My response brought us back to the notion of balance and contrast, and Dylin followed up on this notion with an application of Newton's third law to the appreciation of good and bad.

As the instructor, I would not have thought to draw in these philosophical considerations, had they not arisen from students' thinking out loud. In my reflection on this class session, I wrote of my struggle to decide if these discussions were appropriate for the course. "On the one hand, it is altogether possible that the students take advantage of the open atmosphere to direct attention away from the content they're supposed to be learning. But on the other hand, I established this atmosphere specifically so that we could get into the culturally important, philosophical, meaning-making discussions that physics stirs in people." The deeply nuanced co-construction of the concept of forces in balance, applied in physical, biological, supernatural, and emotional contexts, is a reflection of the interpretive nature of meaning making with science content. In this class, the students connected with the content on a personal level and on their own terms. This dialogue demonstrated the student-driven creation of connections between physical content, usually perceived as dry, highly-technical, abstract, and impersonal, and constructing meanings that were highly personal, value-laden, and tied to deep understandings of the content.

Energy

Energy is a foundational concept for physics, as all interactions that physics studies involve its use or transfer. The concept of energy was an especially rich occasion for meaning making for the students, because it has so many meanings and applications yet is so difficult to define. It is a topic that lends itself well to making connections since we use frequently use the term in everyday conversation, yet it is a very difficult concept to concretely explain, even for physicists. As a consequence, numerous discussions of energy appeared in the data, twenty-three dialogues in all across the whole semester; eleven with Drennan, ten with Dylin, and two with both. The topic of energy, specifically its indefinable nature, also spurred another philosophically-oriented dialogue, from the same session (10^{th} class) from which the metaphorical Newton's third law discussion originated. The first part of this section presents the analysis of the general approaches each student used to learn about energy; the second examines the students' interest in energy and its relationship to life, and includes an analysis of the philosophical dialogue about energy and life from the 10^{th} session.

Approaches to Learning about Energy

Dylin found examples from pop culture that helped him to conceptualize energy, and his descriptions of this concept were clear and accurate; as well, learning about the conservation of energy helped him to clarify his understanding of black holes. Drennan also identified examples in his descriptions of energy, but his examples included a wide array of applications that approximated his multi-faceted understanding of what energy is.

For Dylin, the use of O'odham did not really resonate, but Transformers from the popular culture did. In this selection from the 4th class session below, I introduced the O'odham words for "transform" and "transfer", the two mainstream physics words for what energy can do, that had been provided by the Himdag Committee. (As Dylin was not an O'odham speaker, these words were new to him.) I encouraged the students to put these ideas into their own words, and Dylin took the task in a distinctly pop culture direction.

Me:	The word for transform, [O'odham word]. The word for transfer is more like 'give' really, but it means the same thing. What does transferring mean? What do you think of 'transfer'?
Dylin:	To change?
Me:	It doesn't mean to change exactly.
Dylin:	Oh…I was thinking Transformers! [laughs]

Dylin made a connection between energy and Transformers again in the 5th session, providing evidence that he found this a fund of knowledge useful for making sense of energy. In this case, we were talking about the chain of energy from fossil fuels back to the Sun, and he facetiously included "energon cubes" as one of the sources of energy for animals. He described the plot of Transformers and the role of energon cubes as the following:

> The whole thing was the planet was destroyed, and [the Transformers] are looking for energy, so when they come down to Earth or whatever, what they do is they convert our fossil fuel, like oil and all that, into energon cubes, like these glowy things, and what they do is they put 'em in their chests and that's like, that's their fuel. That's [how they change] our fuel into theirs. So they're just transferring that energy, and turn like two barrels or whatever of oil into one little cube of energy. That's what they call energon cubes.

Although fictional, the narrative that Dylin created around energy transformations and transfers mimicked the scientific narrative of energy chains and put them into a context with which he could relate.

Dylin's definition of energy was concise and straight-forward, with a strong association between energy and motion. In this quote from the 8th class session, he stated,

> Energy is the fuel we need to move across the Earth; you need energy to move about anything. You gotta eat, so we can move, we gotta put fuel in the car. That's the energy for the car to go.

Dylin's mental map of the relationships between these concepts was complex and detailed, as the following excerpt reveals. As previously discussed in the Momentum section, Dylin shared a story about trains from the show Crash Science that he had watched (10th class).

I was watching that the other day; I was thinking of this class the other day. 'Cause I remember how the train built up so much kinetic energy that you can't get rid of it; and they were saying that they have this train, the bullet trains that they have now, take over two and a half miles to stop so they're talking about, that's how much kinetic energy they build up. It takes a lot-, the train doesn't wanna move. The way it's built, and the way it is, like, they don't wanna move, they're built not to move, it takes so much energy and power to get it moving, that it's the same to stop it. They have to gradually make it, even if you slam on the brakes it's still gonna be two and a half miles to try to stop it. That's a long way, Figure, there's no way, if you get hit, it's over. There's nothing they can do.

In his retelling of the episode, Dylin revealed his understanding of the relationship between velocity, kinetic energy, inertia, momentum and impulse: high velocities, such as those possible for a bullet train, "build up" large values of kinetic energy, and trains like this that "don't wanna move" have a great deal of inertia and thus momentum, meaning that it's difficult to start and stop; with this large momentum, it takes a great deal of energy to slow it down, and the impulse if it hits something is enormous.

The law of the conservation of energy is the notion that the total amount of energy in the Universe is constant, meaning that energy can neither be created or destroyed, only moved from object to object (e.g. the energy of wind transferring to water to make waves) or transformed from one kind of energy to another (e.g. electrical energy converting into sound energy in a stereo). In learning about this concept. Dylin was able to work through what had been an apparent paradox to him: black holes. He first hinted at his confusion in the 3rd session, when we were talking about the impossibility of the notion of infinite fuel. [Note: The beginning of this dialogue was included in the first section of this chapter, Velocity & Acceleration.]

Dylin:	What about a black hole? Doesn't it have an infinite amount of energy?
Me:	No…What do you think a black hole is?
Dylin:	It's emptiness?
Me:	No, it's…an imploded star. So it has mass and it has mass that's so strong that the light can't get out once it gets too far in…because it has an intense gravity 'cause there's such a small space and so much mass.

Although we talked here about the fact that black holes are former stars, and thus not, as their name suggests, a space of "emptiness", Dylin likely had years of imagining black holes to be this way from his exposure to science and science fiction movies, documentaries, and novels. It took almost until the end of the semester before he was able to reach a conclusion about black holes that was consistent with his scientific knowledge. Dylin put this scientific knowledge into words in the 4^{th} class with the following wondering.

Dylin:	So does this mean that, whatever you wanna, say Big Bang, that there's only a certain amount of energy that everybody uses at one time…Does that make sense?
Me:	You just accidentally hit upon [the] law of conservation of energy: Energy cannot be created nor destroyed.
Dylin:	So there *is* only a certain amount of energy out there.

Me:	Period. The total amount of energy in the whole Universe is constant. We can't make it; we can't kill it. Nothing can. All we can do is recycle it and pass it along.

Finally, in the 11th class, Dylin was able to express the root of his confusion about black holes and the conservation of energy, and ultimately to resolve it.

Dylin:	[When we] talked about the black hole? The event horizon? It just…that's probably the one that I, I just…I don't wanna say I don't understand it, because I guess no one understands it possibly, but…energy cannot be created or destroyed, but the black hole consumes everything around it…
Me:	It doesn't consume everything around it.
Dylin:	Doesn't it, I mean it sucks in light, I mean it…attracts it, or…
Me:	The light will get too close and not be able to escape gravity…And it's not like that energy becomes gone; it adds to the energy of the black hole.
Dylin:	So a black hole is expanding.

His knowledge of the permanence of energy had been in conflict with his concept of a black hole as an entity that consumes and, in his understanding, destroys energy. By bringing this conflict into the classroom dialogical space, we were able to examine the faulty assumptions underlying it and set them to right. His conclusion, that "a black hole is expanding," while not strictly in line with black hole theory (in which accreting mass is generally converted directly into energy rather than adding to the black hole's mass), was in keeping with the principle of conservation of energy, and was thus consistent with his overall mental map of energy.

In contrast to Dylin's reasonable yet succinct conceptualizations of energy, Drennan's words on the topic appear to be chaotic, drawing in a diversity of examples in a vain attempt to create a clear picture of energy. In the following selection from the 7th class, I was probing Drennan's thoughts about energy, relying on the fact that he likely had a good deal of experience using these words in his everyday life.

Drennan:	My concept of energy would be more towards like force… [but] you have to be more specific. You're talking about energy and power, like a storm has energy and power but so does an electric pole; so does a person, you know?
Me:	I mean all of it. Any way that you can think of that means "power" to you or means "energy" to you. Anything you can think of that has energy or uses energy.
Drennan:	Everything. Like these plants are using an energy, to [photosynthesize]. Cars use energy to drive. There's energy coming off of this [object] 'cause of heat. When you fall down… [laughs] Yeah, basically everything.
Me:	What other kinds of energy are there? Before you were thinking in terms of this class and in terms of science, how else did you think about energy?
Drennan:	Psychic energy…The physical energy that someone gives off. The psychic energy can [go/project] onto somebody, you know? Energy from the Sun; that's the big one out here.

Drennan related energy to the more concrete concept of force initially, then let loose a barrage of examples of energy in use. He did not restrict energy solely to the natural world; his conception of energy included the supernatural. As he correctly noted, energy is possessed by “everything”: he made connections to storms and electrical poles, how plants grow, how cars move, heat energy, the energy of falling, the Sun, and even psychic energy. Later in the class, he developed a metaphor that unified his examples. (7th class)

> Energy’s…I keep wanting to say the life force...It’s energy that makes everything everything. …Makes the trees grow, makes us, makes the stars.

The 10th class, over a month later, brought the topic of energy back to the fore. I asked Drennan to verbalize his understanding of energy, as he might explain it to someone else. He wrestled with coming up with a definition that encompassed all that he understood energy to be.

> Hm, how would I describe energy to a…hm, like, like, ok, I mean, it’s a broad spectrum ‘cause energy comes in different forms: light, sound, um. I mean, look at this, there’s solar winds, and there’s no wind up there, you know? You know what I mean? There’s no clouds or wind or stuff like that; it’s radiation. How would I describe it, hm. I’m trying to think, how would I describe that…[silence] It’s kind of a good…I keep thinking like, these little things. [To Dylin] Like the broader spectrum, like what, how could you explain it? Kinda like not the action but what it causes, or what it [affects]?

Drennan seemed to be struggling with the notion of energy creating a force without being able to touch an object. He recognized that energy is not necessarily a tangible thing: he had to include the energy of light/radiation, and things like the solar wind (which actually is matter, but matter traveling across empty space unlike Earth wind). Drennan again showed his difficulty in distinguishing between force and energy in this excerpt from the 10th class, his response after being asked to define force.

Drennan:	Force to me is like…energy to do something. Like this bottle; it'll just sit there if nothing acts upon it, you know. If there's an earthquake, whatever, its kinetic energy will go through the ground and cause this to shake. Same thing with like a ball, it won't just roll around. Even the water inside [the bottle]…if nothing acts upon it, it'll just be there….Or heat even, if heat acts upon it it'll start to boil and it'll start to move. The molecules inside it will start to move. And so that's my personal definition of force.
Me:	Which part is the force? How do you isolate…what part of it is the force?
Drennan:	I would say the energy that…causes things to happen.

Drennan's difficulty in teasing apart energy and force is understandable, as the distinction between the two is subtle at best and non-existent at worst. Physicists often talk about how we can't "see" energy unless we see its results; it was these results that Drennan was referring to with his connections to light, sound, wind, and "action" in the first excerpt, and transfers of kinetic and heat energy in the second.

Power is defined in physics as energy over time, but can be interpreted colloquially as energy use. In Drennan's response to the following question about power, the crux of his difficulties in defining energy and force was made evident (italicized for emphasis).

Me:	When you talk about power what do you mean?

Drennan:	*It has to be in whatever context.* You have power over us because you're giving us our grade. That plane is using power. It's got power 'cause it's using energy to thrust itself through the atmosphere or through the air.
Me:	So if I have power over you, what is that then? What's the difference, or is there a difference?
Drennan:	It's just a different kind of power. Just like a marshmallow. [A] marshmallow has power; it's just how you use it. When we absorb a marshmallow we're getting energy and power from it because of the sugary stuff, but if you drop a [marshmallow] on a neutron star the gravity gives it the power to explode like a nuclear bomb.

Drennan talked in this selection about the importance of context for understanding energy in all its manifestations. He had talked before about specific happenings that occur because of energy: growing trees, people, and stars. His conceptions of power were similarly contextual: he talked about the power of status, motion, and food. The point he makes about energy being different depending on its use is valid: humans can absorb so much of the energy of a marshmallow as a food source, but if the mass of the marshmallow were converted into pure energy, for example by being dropped onto a neutron star, the power would be enormous.

A little later in the class, Drennan thought of another example of power in context, where for an African tribe on a show he watched, the ability to withstand pain was a show of power.

> The guys get the stick, like they whip each other three times. If you're able to take it and smile and not cry or nothing…some of those dudes collapse in pain…if you take it then you're a man….Their sisters and girls in their family, they egg on these certain guys that have already gone through it to whip them, and they get all these scars showing that they're like 'yeah, yeah, our family's got, our family's bad.'

Within this context, power is social status, and social status is a metaphor for the ability to "make things happen", as Drennan described of energy. Finally, in this last excerpt from the end of the class, Drennan was speaking just off-topic as we were wrapping up our activity, and he triggered for himself another example of power in context: knowledge as power. Even getting to know people was, for him, an instance of developing power through social status.

Drennan:	Just like a couple months ago I didn't know any of these people.
Me:	Now you know everybody. How did that happen?
Drennan:	Education. Power! Knowledge.

For Drennan, it was possible to define energy generally (e.g. "life force…that makes everything everything"), but ultimately such definitions were meaningless outside of a context within which energy was manifested. His definitions were not chaotic because he did not understand energy, but because he did; he saw energy as a part of everything, and it could not be separated from objects and events.

<u>The Relationship between Energy and Life</u>

The fact that the students saw life and energy as one and the same was one that took me, as the instructor, almost the entire semester to fully recognize, despite the fact that there were plenty of indications from students' dialogues along the way. Both students engaged in dialogues about the applications of energy to life, each considering different implications. Drennan began talking about the relationship between life and energy from the very start of the class and incorporated this relationship in many of his discussions of energy, notably in the 12th session but elsewhere throughout the semester as well. Dylin made reference to this relationship also, and elucidated it for the whole class in the key 10th session dialogue.

As mentioned above, Drennan made several interesting comments relating energy and life throughout the semester. In the 1st class, he described an idea he had for a lab experiment – creating fire by rubbing sticks together.

Drennan:	Rubbing two sticks together to make a fire; wouldn't that be a good experiment?
Me:	That would go in, kind of energy and work…
Drennan:	Energy, like the energy transfer, one energy to another…Even when you make that fire, the heat's gonna come back to you and warm you up.

His comment seems unremarkable at first, but in fact he was making use of the notion of the conservation of energy long before we introduced it in class, presenting a chain of energy in which a person uses their mechanical energy to rub the sticks together, which creates fire, whose heat energy goes back to the person. We elaborated on this chain of energy idea in the 12th session, tracing nearly all energy of life on Earth back to the Sun.

Me: [Our energy] can go back into the environment…The waste that we produce, say like the body waste, goes back into feeding some bacteria, which goes to feeding some small organisms, which goes to feeding some other organism, and so on and so on.

Drennan: That's weird…So everything really is connected together… Like the energy of the Sun is just feeding everything pretty much.

The person is powerful in Drennan's conception of energy. For one, each person emits energy, as Drennan posited in the 2nd class: "The human body does emit…a magnetic force, you know? Everything living emits a energy force." And the energy of people influences the outside world, as Drennan explained in his interview when asked what other topics a physics class at the college could include.

We coulda measured how people use the desert… Because like the rain dance, it's everybody just focusing their energy on bringing the rain, you know? And that would have been interesting if we could have measured their bodies and everything - just to see how it works.

This application of energy was not supernatural but simply natural in Drennan's world. His reference to human energy bringing the rain related to his wondering about humans being able to project heat energy in the 14th class, as discussed in the Fields section. He was interested in how the body and life in general uses energy. His dialogue from the 12th session delved into this subject, following up on the chain of energy to the Sun that we discussed previously.

Have they ever measured like a person's energy through his whole life? Like let's say someone lives to be 80 or 99…Children, I know their bodies are smaller but don't they burn more energy than adults do?...Have they measured a plant's intake?...I mean obviously different plants will use different amounts…And I'm wondering of all the power the Sun gives…how much of the sunlight does the planet absorb on its creatures…Like let's say, how much energy was absorbed last year…by life.

Drennan's curiosity about life and energy tied to his interest in other scientific topics as well. As noted in previous sections, he often introduced wonderings about animal intelligence, such as in the 10th class during our discussion about conflict and evolution. In the 12th class, he sought to make a connection between intelligence and energy.

Drennan:	It all comes back to energy…How it's used for different things. I'm sure your heartbeat is a certain amount of energy, but it's probably not as much as your brain, or it might be more.
Me:	Probably your brain uses the most. I would guess.
Drennan:	The more you're working the more you're thinking the hungrier you'll be? ...'Cause a large brain takes a lot of energy to use. That's how that came up in my mind.
Me:	For sure I would think that having a larger brain would need more energy, and having a larger brain is related to being able to have higher order thinking skills.

Drennan:	Learning and instinct, do they use the same amount of energy? Like plants in Africa, I forgot their name but when the giraffe just eat them they know that they can only eat so much. 'Cause this tree…after the giraffe eats so much it will emit a poison to every leaf in the system so the plant dies. So the giraffe stops eating before that poison is emitted…What it looks like, it's like trees communicate through chemicals, and if so are they thinking, [or] is it instinctual...How does that work and what is the amount of energy needed if it's thinking at all?

What these connections implied was that Drennan's main scientific interest was in fact life, and he used the knowledge he was gaining in physics in an effort to better understand life. In our conversation in the 7th class when asked to define energy and explain what it means to have spirit; he replied, "To have spirit is to have energy." He was quite possibly dodging the question by equating spirit and energy while defining neither, but his response implies a parity among spirit, energy and life that helps in interpreting both his and Dylin's views on the topic.

Dylin took learning about energy, and in particular the conservation of energy, in a similar direction. In the 8th session, we had a comparable dialogue about the chain of energy, which Dylin tied to life and in particular to creating new life.

Dylin:	So how does [the conservation of energy] work with human life, or life that is created?
Me:	We're not talking about life. We're talking about energy.

Dylin:	But we have movement. So we have energy. So does that mean we're deriving that energy from the initial burst of energy?
Me:	All energy has always been here, will always, in the whole Universe, will always be here. Any energy that we use has been recycled over and over and over again. So we get energy from the Sun. And that's always coming to the Earth.
Dylin:	So we consume that energy, using the Sun rays to create life…so we're just recycling the energy of the Sun.

The excerpt above contains several of Dylin's ideas about the relationship between energy and life. His question about creating life relative to the conservation of energy implied that for him "creating life" and "creating energy" were the same, and thus birth was inconsistent with the physical constraint that energy cannot be created. Dylin also equated energy and motion, in keeping with his definition of energy as fuel for motion. As Drennan did, Dylin realized that all life is using and recycling energy from the Sun, though this notion brought him to a distinctly different conclusion.

Dylin:	Is this where the soul derives from, I mean as far as energy? People say when you die you can't destroy the energy. You still have it. So is that kind of where…is that [possible]?
Me:	It could be. I mean, who knows? The energy is being recycled.
Dylin:	Yeah, but where is it recycled to…are we born with a certain amount of energy and that's our life point? You know people read palms. That's your lifeline. You use up that energy, then you're dead…You know as we're doing

> this right now, I'm burning up whatever initial energy I've had to begin with in life. Maybe that's why there's ghosts, 'cause most spirits are people that died too soon so they have that energy that they never got to use up…so now they're using up that energy in a different form.

Drennan may have agreed with this conclusion too, had he been there; both students saw little or no boundary between the physical and the supernatural, and found ways to apply physics to understanding ideas that, from a Western science perspective, fall outside the purview of science. Dylin's conclusion above relied upon an extension of the conservation of energy, in which there is only a given amount of energy in the Universe, to the life of the human body, in which there is only a given amount of energy allotted to each person for their whole life.

My response in the previous excerpt that differentiated between life and energy, predicated on my Western science-oriented understanding, was probably very confusing to Dylin, though I did not realize that at the time. My role as devil's advocate was reprieved in the following dialogue from the 10th class, which was sparked by asking the students to explain what energy is in their own words. As previously mentioned, this is a difficult thing to do; we all think we know what we mean when we say "energy" but it is very hard to explain it. The students, first Dylin and then Drennan, posited that energy is life, echoing Drennan's "life force" comment from the 7th session. Building off each other, they went on to elaborate on this point. I honestly did not follow the logic at that time, and I resisted as I tried to wrap my mind around it; the students expressed agency by pursuing their ideas despite my insinuations that they must be wrong. The excerpts that follow are long, but were chosen for their illustrative content.

Dylin:	Energy is…it's life.
Me:	Is there energy in things that are dead? Is there energy in things that are non-living, like this desk? Like the computer?
Dylin:	Everything has energy.
Me:	Ok, so it's not just about life, so what is it?
Dylin:	But the things that are dead help contribute to life. So, in that theory, even the dead things, even decomposing bodies, even the desk, helps us.
Me:	What about things that are nothing to do with life? Like black holes? Do they have energy?
Drennan:	They have unimaginable energy. It can't even be measured how much energy they have.
Dylin:	But they have to do with life too.
Me:	How?
Dylin:	Because they have their place in the galaxy. Who's to say if we didn't have black holes…maybe black holes is the garbage disposal of the Universe and it's getting rid of all the crap. And if it wasn't [for] black holes, then we'd have all these asteroids flying around hitting Earth, or hitting other planets. They serve a purpose in the Universe, so in their own way…even like mosquitoes; no one likes them, but they get eaten by bugs, the bugs get eaten

by birds, you know, so on and so forth, they serve their purpose. Same thing with a black hole; it's there for a reason, it's sucking up garbage.

Me: It's a philosophical question, but to me the Universe is far more vast than has anything to do with life. Life is so localized, at least as far as we know, to this time and this space, and there's so much more energy in the Universe that has nothing to do with us. But again, you could spin it either way. Maybe it all comes down to life.

Drennan: It's hard to think of something that's not connected to life.

Me: Really?

Drennan: Yeah; even things we don't know about would still affect us.

Me: How does another galaxy affect us?

Drennan: Even if we don't feel it, we can see it, so its light can be detected by us, and our brain starts thinking about 'what's there? how is that?' and that *itself* forms energy in your mind.

The students demonstrated in this excerpt that they put life at the center of the Universe. Dylin expressed the view that all things in the Universe serve a purpose, and the purpose is to support life; he related this notion to the cycle and balance of life on Earth. Drennan took another angle, stating that even things that, in my mind, have "nothing to do with us" still affect life because they affect our thinking and thus our energy. Dylin elaborated on this point in the following excerpt, and also made a connection between this view and the students' culture.

Dylin:	I think we're talking like this because of [our] tribal [beliefs]. Tribally, most people think, believe everything's here for a reason, everything has to do with life. It's like [the] butterfly effect…you throw a stone in the ocean, who knows. The ripples could come and cause a tsunami and kill thousands of people, you wouldn't even know. Yes, the rock isn't life, [it] has nothing to do with life theoretically, but the action that it caused will affect life, maybe…however long it takes. Will the galaxy affect us? We don't know. Yes and no. You can say no, you can argue no; you can say yes, you can argue yes, but the fact is, neither one of us are right. 'Cause we don't know; we haven't gone there, we don't know if there's life, we don't know if there are aliens visiting us and either helping us out or not. The black hole…everyone's theorizing on exactly what it does; it's gotta be there for a reason. I wouldn't think that there would be a black hole for no reason. There's gotta be a purpose for it.
Me:	A purpose for the life of the galaxy?
Dylin:	Yeah. It's kinda like in order for a planet to have life, it has to have all these things go right. Maybe for the galaxy to have life in it somewhere, there has to be a black hole, it has to be this size, it's gotta be doing a certain amount of things, it's gotta be really complicated. In order to sustain life somewhere in that galaxy, you have to have certain things, and maybe that's one of them.
Me:	That's an interesting point.

Drennan:	'Cause you never know what life is. I mean, for example, Jupiter has giant storms on it, and they get bigger. We could call it growing, growing by absorbing the other storms [that] you could say they were eating. So you could say they're existing, growing, even eating; I mean isn't that the definition of life? It's just like another form of life, maybe…People would think that that has nothing to do with life, but in actuality that right there could be the creation [on] another planet.
Me:	Could be its own form of life. That's another point too. It has nothing to do with us, but it has its *own* life to take care of. It has its own life cycle.
Drennan:	But energy itself, I guess you could say it's the source. The source for everything to become what it can.
Me:	So energy is basically the *thing*, whatever it is, that makes things happen.
Dylin:	The source.
Me:	It's the source, but it's also the flow; I mean it's not just where things start from, it's what things are.
Dylin:	Everything already has energy.
Me:	Oh yeah. *Ev*erything already has energy; there's nothing in the whole Universe that has no energy.

Although I am generally not attending overly much to false starts in the dialogue, the fact that Dylin switched from "think" to "believe" when describing the tribal value of the centrality of life was telling. It seemed to be a concession to me in recognition that although it may not be "scientific" to ascribe to this idea, people nevertheless believe it.

In this spontaneous vocabulary switch, he drew a line between (logical) thought and (emotional) belief. He then made the point that we can't know these things (e.g. what's happening in another galaxy or in a black hole), we can only theorize. Drennan picked up on this idea that there are limits to what science can tell us when he talked about the life-like qualities of storms. Dylin referred to the fact that neither of us is more "right" than the other because there is no way for accounting for every influence from every direction in the Universe – perhaps a gentle reminder to me that the Western science Discourse has no more the authority than the O'odham Discourse, and my ideas are no better than anyone else's. In the end it's all speculation; none of us really knows the "truth". Although this might resemble the "God of the gaps" role of spirituality and religion in understanding the natural world, it actually goes beyond this simplification; even if we knew absolutely everything there was to know about life and the Universe, there would still be space for the students' belief because it pertains to the "why" not the "how". There is life in the Universe (scientific fact) because life is important (philosophical idea).

Drennan described energy as "the source…for everything…to become what it can." This again seems to go back to the idea that life is central: energy is the "source" for all things' potential. Energy is like "life force", a well of potentiality from which all things can draw. The students envisioned a Universe of entities, large and small, that go about their lives, and energy is the fuel that powers their lives. The fact that life is important was the keystone of the students' understanding of how the Universe works. This is critical for physics instructors to know as they frame courses for this population of students. If the students and I had been on the same page about life and energy from the beginning, or if we had been from the same cultural background and shared these values, this conversation would have unfolded in a certain way and potentially been a wonderful avenue to broadening students' conception of energy. As it was, the tension and conflict between our hybrid perspectives led us down a very different path – a path toward a new conception that stretched all of us beyond our comfort zones, yet which resulted in a more nuanced conception that integrated elements of all perspectives; our conversation unfolded in a very different but no less wonderful way by virtue of our diversity. Each of the components that factored into the development of third space also contributed to the students' conceptual understanding, and mine as well. By the end of the discussion, we had reached a broad understanding of what energy is, and this broad understanding was rich with complexity as a result of the multifaceted perspectives brought into play during the discussion: energy is life, or it isn't life; it is the source of potential for all objects in the Universe; it is that which comprises all things; it is that which makes things happen; and everything in the Universe possesses it.

This co-constructed dialogue gave me access to the students' culturally-based assumption about the natural world, of which I would not otherwise have been aware. The whole conversation from "what is energy", described here, to the importance of conflict, described in the section on Newton's Laws, took only about an hour, and this was an hour in which other things were also happening – Dylin was building a rocket-powered vehicle and Drennan was reviewing a chapter on momentum. One hour out of a semester-long class to create meanings that literally changed the way I think about physics, and I can only hope had a fraction of this impact on the students.

Nature of Science

One of the central learning objectives of any college introductory science course is to give students exposure to the processes and epistemology of Western science, and this course was no exception. However, in light of the fact that this course employed a critical pedagogy and took place in a tribal college setting, this objective was expanded to encompass the view that science is a global phenomenon, of which Western science is but one example, albeit a socially dominant example at this point in human history. Fifteen meaning-making dialogues occurring in nearly every class session were identified for this topic: five with Drennan, five with Dylin, and five with both students. This section is presented in two parts; the first presents the analysis of how the class came to an understanding of science as occurring within cultural settings, and the second presents each student's individual journey in developing a critical perspective of science.

<u>Science as a cultural endeavor</u>

As a counterpoint to the implicit message from most mainstream sources that science can only be done in certain ways by certain people who think a certain way, we identified ways that science, as an activity designed to build understandings of the natural world, is practiced and applied by all people in all facets of their lives. The recognition that students have a valuable scientific heritage, the second principle of culturally-relevant science curricula, was built into the course philosophy as an awareness that students' culture, both modern and traditional, is replete with sophisticated understandings about the natural world (Cajete, 1999a). Our discussions about the nature of science framed science as an endeavor arising within cultural contexts – in the case of the local culture, as the development of understandings allowing the people to live and thrive in the desert environment. For instance, the O'odham have a sophisticated understanding of weather patterns and the water cycle in the desert that allowed them to shift their communities' locations with changing seasons and to raise crops with infrequent rain.

Looking at the influence of culture on science ties back to the notion of maintaining a critical stance toward science, in that viewing science as only one of a vast collection of culturally-specific sciences challenges Western science's position of dominance. This approach was introduced in the 1st class with Drennan, and in the 2nd class with both students but particularly for the benefit of Dylin, who was attending the class for the first time. It was crucial for our success that students realize that the fact that they came from outside the dominant culture was a benefit, both to them as science learners and potentially to the advancement of the field of science, as the ability to look at the world from different perspectives is essential for developing scientific understandings. The discussion in the 2nd class emphasized the importance of looking at the world from different perspectives, and the fact that these different perspectives flavor the meaning that we make of our scientific knowledge.

Me:	Where does culture come into [science]? Where does your point of view have an impact on what you do with science?

Drennan:	I think it depends on the person doing the experiment; they can be biased one way or another way.
Me:	Ok, so a person can be biased. Where does your bias come into play when you're doing science?
Dylin:	The biggest bias that would be out there would be religion.
Me:	Ok, so a person's religion can be a bias. Now, bias kind of has a negative connotation to it, so let's use a different word for it: a person can have a certain point of view. A person can have a perspective, a worldview, a philosophy, a lens. Do you know what I mean by a lens? Think of it visually; what does it mean to have a lens? We're all wearing glasses; what does it mean?
Drennan:	The way you see things.
Me:	Right. It's what you see things *through*. It's your filter for the world.
Dylin:	So how can anyone truly be objective; I would think that's impossible.
Me:	That's what we're talking about. It's impossible to be 100% objective. There's always things that are coloring the way you look at the world; you always have a lens. What are some other things that can affect your perspective?
Dylin:	Maybe your location on the world.
Drennan:	Background.
Me:	Mmhm…all these things affect your perspective. How does your perspective affect the way you do science?

Drennan:	Well, would it affect your data? No matter how it comes out, your bias [would affect it].
Me:	It could; if you are not careful about being honest with your data, you could impact what you see, so your observations.
Dylin:	It affects everything. Obviously your hypothesis, all your opinions [that drive] everything else, including the laws; I mean, it affects every single one of these steps in science.
Me:	Exactly. So it can affect your theory, and perhaps even your laws. Theories especially, because theory is your explanation, so this is where your own creativity comes in. [It's] the way you interpret the data. The way you interpret something is very much dependent on your perspective…The Universe is out there for everyone to look at. But your lens is gonna affect the way you see it. So that's why there's more than one physics, and more than one science.

This discussion put the idea of science as cultural into a context for the students to understand. Science itself is a negotiation between the natural world and the human interpretation of it. As the students and I discussed, though the natural world may be the same everywhere, as different people and different cultures interact with it, the perspectives that they bring to understanding the Universe will ultimately create a science that is tailored to that interaction. Thus, science can be viewed as emerging from and being employed by cultures, who bring their worldviews to bear when they engage in the construction of scientific knowledge. Viewing science as imbedded within cultural perspectives was a means of mitigating the conflict and tension that may arise as different perspectives come together in the shared classroom space.

The next step in our critical journey was interpreting the text as a cultural artifact rather than an authority of physics. The book was treated as a jumping-off point for making meaning with science, which again would be personal to the students. We talked about this in the 1st class with just Drennan, and in the 4th class with just Dylin. The students were encouraged to use their textbook as a resource to start their thinking about new concepts, but to read it critically and be aware of the assumptions it made. The text was presented to the students as a one-sided story slanted toward the perspectives of those from the dominant culture, in particular the subculture of Western physicists, in the hope that they would view their textbook not as representing absolute truth but as a jumping off point for creating their own interpretations.

Another essential component to the class' ability to take a critical stance was having a shared vocabulary. The New London Group (1996) emphasized the importance of *metadiscursive awareness* for developing critical literacy, where the differences and interactions of different Discourses are made explicit; for instance, discussing the ways that science Discourse uses terms and concepts that are used differently in other Discourses. In the 2nd class with both students present, we deconstructed several contentious elements of the scientific Discourse: theory, hypothesis, prove, and experimentation. This was a foray into the way that Western science "thinks"; we were again treating Western science and its Discourse as cultural artifacts that are not absolute but rather defined and used by people. Examining the Discourse of Western science, comparing it to the Discourse of everyday language, and looking at the interaction of the two helped to support the idea of science as one of many culturally-constructed ways of knowing.

"Theory" is a controversial concept for the very reason that it is used to mean two different things depending on its context, so there is a high probability of conflict when these meanings are used side by side without an awareness of their differences. Unpacking these meanings was a key component of developing the students' discursive literacy. "Prove" is another loaded word in a scientific context; we typically think of something "proven" as something incontrovertible, absolute truth. It is not uncommon to hear phrases such as "Science has proven…", but Western science cannot lay claim to absolute truth. The excerpt below (3rd class) provides an example of a discussion about a discursive tool, in this case "theory".

Me:	What is theory? We talked about that having two meanings.
Dylin:	They're something that's more solid, but has something to do with your opinion as well.
Me:	Yeah. So on the one hand in common everyday-use theory means 'opinion'. It means kind of like hunch…In science what does it mean?
Dylin:	You have a good idea what it is, or you checked it out a few times and it's coming out the way you thought it was going to be, but it's obviously not proven or disproven.
Me:	Right. It can never be proven, but a theory is a very well-established explanation that accounts for all the data. And again it could still be wrong

because nothing can ever be 100% right, but as you learn more and more and gather more and more data, your theory becomes stronger and stronger, because as you change it, it becomes closer to what the physical world suggests.

Although more of a process than a discursive tool, we also looked at the role of experimentation in Western science. The students began talking about experimentation proscriptively, as a procedure that must be done correctly, so we emphasized the role of experimentation as exploration, distinguishing between experimentation and demonstration which the students seemed to be conflating.

Dylin: Are we doing the experiment correctly, and is it working every single time we're doing it. So that way, we're like "check this out!" we put it together and it doesn't work. [Drennan and I laugh] And we're like "um, it worked last time, I swear!" That's the kinda stuff we start working to, to learning how to do these experiments correctly rather than writing out how we did it.

Drennan: Yeah, I know what he means…Like an experiment, maybe a small or a quick summary about what it's gonna do and then how it's gonna do it and then show them what it's gonna do. We just say, "this is called, whatever whatever" and then, bang….I mean, all we're trying to do is to prove what we've learned, right? That's the whole point of it.

Me: Yeah. Right. But experiments, experimentation…there's no right and wrong way to do it. I mean, if you wanna have a reaction happen and it's not happening, then your demo's kind of a failure. But if you wanna show

> somebody how science works, there's, there's not an end goal, necessarily, 'cause it's an open-ended question. If you really wanna learn something about the world, that answer is out there, but you don't know what it is yet. So, setting things up in a certain way, yeah that's important, because you wanna make sure your experiment is valid. But, if you don't get the result you expect, it doesn't mean your experiment didn't work.

Examining the Discourse of Western science, comparing it to the Discourse of everyday language, and looking at the interaction of the two helped to support the idea of science as one of many culturally-constructed ways of knowing. It was also a means of helping the students to view science not as written rules proscribed by a mysterious other, but as a process of learning and discovery that is continually in progress. Below, I present how each student in turn came to a more nuanced understanding of the nature of science.

Journeys to develop critical perspectives of science

The two students in the class were very different people with very different journeys through the course. Both the students took on critical perspectives of science over the course of the semester, but the perspective of each was quite different from the other, depending on each student's individual background, positioning with regard to science, and personality. In this section, I illustrate the path taken by each student with excerpts from his spoken (and in the case of one student, also written) discourse.

Drennan's Journey

When Drennan began the semester, science was already a part of his identity. He referred to himself as someone who had "always been a science nut, messing with things". He described himself as a hands-on person who "wanted to be the next Carl Sagan". He admired Stephen Hawking and liked thinking about all different varieties of scientific theories. What he had hoped to gain from this course was "a better understanding of the world and the Universe…Instead of just the regular Big Bang Theory or something like that, you know?" He came in on the first day of class already brimming with questions he wanted to ask and experiences he wanted to share, as evidenced by his sharing of this plasma ball story in the first half hour of class.

> I know…when gas is heated up it turns into plasma. Does plasma turn into anything else? …I actually had an experience with, you know, a ball of lightning…plasma balls? Our neighbors across the street, the orb actually, a plasma ball actually came into their house, it came through the roof, it was during a lightning storm, and it went along their table…They didn't know what it was, but I knew what it was as soon as they told me what it was, they thought it was like some something, a spirit came, and I told them 'no, it was a ball of lightning, you know plasma.' It was crazy…That's why I was just wondering if there are any other states past plasma.

He was always thinking about how the world worked, and what it meant to him as a human being. In his interview with me following the end of the semester, he talked about identifying as a science lover. I asked him if his impression of science had changed after being part of this class.

> I've actually understood a little more. I've understood a little more. But it's just, like I said, another tool to understand the Universe. I've always been into science, so. Either way, for me it was cool.

In his polite way, he was saying “no”, that his impression of science had not really changed because of the class – he had always loved science and he continued to do so. What he gained from the class, rather than a change in perspective, was increased understanding. He described how becoming more knowledgeable allowed him to take on more of an expert role amongst his peers.

> People should understand physics better, and it would just be so much cooler if more people would wanna learn about physics, ‘cause they are fundamental truths that everybody needs to know, sooner or later…And I’ve shown some of my friends the stuff, like “yeah I was doing this!” You know, they’re like “Whoa! Really?!” And I just tell them, “It’s not really that hard, you just have to know what you’re talking about.”

Drennan viewed himself as a science learner. He was eager to ask questions and seek answers, and science was a natural fit for him. My one-on-one dialogues with him reflected this integration of his academic/scientific and personal identities; they were free-flowing and made connections between his outside life and life inside the classroom. The following dialogue from the 9th class, as Drennan was constructing his Newton’s 3rd law-powered vehicle for the midterm engineering component, is an illustrative example of this integration. The academic part of the conversation pertained to Drennan attempting to create a baking soda and vinegar reaction in a balloon to fuel his car; while he built and tested different mechanisms, we chatted about other physics-related and non-academic topics, most of which were introduced by Drennan himself.

Drennan: Did you ever play any sport?

Me:	Not really but I played field hockey for a couple years when I was in junior high.
Drennan:	Do you know when the circus is coming to Tucson?
Me:	I didn’t know it was.
Drennan:	‘Cause I want to go to the circus. I want to go to the zoo and the circus for some reason, it’s been a while.
Me:	You could do that for a physics lab. Barnum and Bailey.
Drennan:	I think you’re supposed to make balloon animals out of these. This could be the body.
Me:	But they’re so fat. They’re too fat to use.
Drennan:	We could make a turtle. What did you think of the new movie?
Me:	Oh, terrible. The PG one?
Drennan:	Yeah.
Me:	I didn’t like it at all.
Drennan:	Does vinegar do anything besides smell?
Me:	You can use it for cleaning, but I don’t know what it does.
Drennan:	Have you ever made something blow up using that?
Me:	No.

Drennan: But let's say you had a very large amount, would it explode?

Me: If you build up enough pressure and it was too much pressure that the thing…couldn't handle it, it would break.

Drennan: Maybe it doesn't need so much air.

Me: Maybe so. Maybe if you put it on the track it would stay on the table and wouldn't bounce around so much like that.

Drennan: Might just turn. No, I just flipped it over. I could just tie it on there and let it pull like this. Like…in [Star Wars] Episode 1 how they pull it along like that.

Drennan: When you're driving in what do you listen to? Do you listen to music or the radio?

Me: Usually the radio. Music on the radio.

What was so interesting about this dialogue (one of many examples that could have been chosen) is how it went back and forth from the official academic space and the third space. Drennan and I co-constructed an understanding of how to engineer a vehicle that would use Newton's 3rd law and travel in a particular way according to the specs – something that neither of us had done before – so there was a great deal of experimentation going on while we bounced ideas off each other. Drennan experimented with both gas-powered and air-powered balloon vehicles and we talked about how to make them work. The open-ended nature of the exam and the interactivity of the classroom created this space for student voice, but Drennan's personality and science-inclusive identity made switching back and forth from academic to personal easy and comfortable.

However, Drennan was not always in sync with the dominant science culture. Later in the ninth class, the same one from which came the long dialogue above, he was working on a problem on the midterm about the trajectories of rockets.

Drennan:	So it didn't travel did it? It didn't travel, it just went up and down.
Me:	If there's nothing else going on. I mean that's not really gonna happen 'cause it's always some reason it's gonna go [off] but if everything's perfect and it went straight up and straight down…
Drennan:	Oh, so it's a trick question.
Me:	It's not a trick question.
Drennan:	I was just asking a simple question.

Drennan challenged the question that was asked, expressing a critical perspective of science by objecting to the idealized way that mainstream physics approaches problems such as this one. The scenario he was responding to was modeled on ideal conditions, which did not closely resemble reality, including his own lived experiences with the rockets we had used in class.

Drennan further fleshed out this idea toward the end of the semester, during the 12th class session when it was again just him and me in class. In the midst of a conversation about teaching and thinking in the animal world (which stemmed from our previously-described discussion of how life uses energy), Drennan voiced his interpretation that, rather being *the* authoritative source of all knowledge about the natural world, Western science does have limitations. In reference to learning and instinct in animals, he said the following:

> It's like physics is putting numbers to things to understand it, and it's like how do you put numbers to *those* things? Like an act; how do you put numbers to an act? …You can measure it, but how about up in here [in the mind]? They measure the time that it takes for the light to hit your eyes and go to your brain, but what about after that? Can emotions be measured too? Say, put a lion in there, [and] if he's happy he goes like this; but why?

As this quote reveals, Drennan was able to recognize that while mainstream physics can address some questions – it can "measure" and "put numbers" to things, a very quantitative based of knowledge – it does not pertain to how human beings interpret the natural world, nor is it able to address the *why* of natural phenomena.

Drennan's perspective of science evolved over the course of the semester; he described what had changed for him in his interview with me, an excerpt of which is below. I asked him if he had ever thought of science as being cultural before he took this class. He responded,

> No, not really. Not really. I just looked at science, science just as straight-up truth. Straight up, right there, a tool. Not really like, "well if it wasn't for that, we wouldn't have found *this* out," you know. If it wasn't for our ancestors, we wouldn't know that we could do this….I mean like the lights and stuff like that…if no one had messed around, we wouldn't know.

Drennan's view of science evolved from thinking of it in absolutist terms ("straight-up truth") to thinking of it as something discovered and passed down by our ancestors and integrated into our culture. He also described the process of building knowledge over time ("if it wasn't for that, we wouldn't have found *this* out"; "If it wasn't for our ancestors, we wouldn't know that we could do this"). Once he began to see science as cultural, he was able to extend this perspective to one which viewed science as belonging to all peoples and all cultures, as well as specifically to his own culture. His already inclusive view of science, in which science belonged to him and was a part of his identity, was expanded to one which recognized that science belongs to all and is part of our cultural identities. In the following excerpt from the 12th class, he talked about seeing oneself as a scientist and a learner, something that he believed was everyone's right and part of everyone's potential.

There's just so much stuff out there and a lot of people have this misconception of themselves that I can't be that, I can't be that…An astronomer, a scientist, I can't be that. Everybody's a scientist at heart. Always wondering about stuff and thinking…It's just interesting that there's so many opportunities right there. That's why this college is like a stepping stone…It's a doorway to a bigger world, a bigger and better world…I'd rather do this [than other things] because in the long run this is gonna pay off, and when I'm old I can say, you know what, this is what I did; you can do this or better. It's just out there. I mean knowledge is power, no matter what it is…I can't see how people don't want to do this, it's just strange for me. Like their eyes are closed and there's more than that. Even this, who knows, they could be the next person to go to another planet because they discover something. They don't know.

Drennan viewed education and learning as a means to get out of a cycle of self-destruction and as a hope for a better life. Science was a part of that for him, because science was a natural process of coming to learn about the world; he tied everything back to science and humans' natural curiosity to wonder and seek answers. We had also discussed more of this idea in reviewing his essay from the midterm (the hardcopy of which was sadly lost) during the 10th class.

Me:	So in your first paragraph, I can see where you're saying…how scientific things influence culture, and then how that…led to science? Right? Is that your idea?
Drennan:	Yeah…'cause everybody that's bored and started experimenting with something. I was actually gonna…use gunpowder, with hunting and stuff, how we started hunting; gunpowder made our life easier.

Drennan's essay discussed the role that new scientific information could have in the evolution of a culture, such as with his example of how guns changed the culture of hunting for the O'odham. Again, he also expressed his interpretation of science as belonging to everyone, as an outcome of his belief that science comes naturally to humans.

At the end of the semester, Drennan submitted a series of journal entries relating to reading from the text. In one of these in particular, he further elaborated on his perspective about science.

> As a child I was always into science fiction. I noticed that heroes wouldn't be able to face the obstacles and challenges without the help of the scientists to help them figure out a solution to weaknesses in the armor of the enemy or what have you…If it wasn't for these scientists to take theories or invent weapons and discover new things nothing would happen. We would be individuals roaming the earth just happening into things without thought or wonder. But this is not so, we are all creatures filled with inelegance [intelligence] and curiosity. Maybe it's a survival instinct to make things better for [our] genetic line of existence. Could it be destiny, who knows but one thing is for sure we are all biological learning machines. This is why we notice and are very observant. By discovering we enhance not only our intelligence but our capacity for thought.

While valuing the input of professional scientists with a connection to superhero stories, Drennan wrote that everyone is a natural-born scientist. His use of pronouns is telling in this excerpt; at first he said "the scientists" and "these scientists", making scientists seem like a category of people distinct from the rest of us, without whom we would all be aimless, thoughtless wanderers. In the middle of his writing, however, he switched to "we" and "our", showing possession of the traits associated with science and extending them to all people. Drennan's comment that "we are all biological learning machines" is a succinct and eloquent summary of his position.

Dylin's Journey

As previously mentioned, Dylin's journey was markedly different from Drennan's. He had a different background and came in with a very different perspective from Drennan's strong identification with science. Dylin entered the class with a "science is absolute" perspective of science. When I first introduced the idea of a culturally-based science course, at the start of the 2nd class (his first class of the semester), the following exchange took place.

Me:	It's supposed to be a culturally-relevant physics course. So, the benefits of taking it here is that you take it from an O'odham point of view. Or you *provide* the O'odham point of view; I can't give that to you.
Dylin:	But isn't this all, isn't physics all relevant? I mean, isn't it all, no matter where you're at, it's the same?...I mean I don't know how; you can incorporate the culture in some ways with experiments and do culturally relevant, but I don't think physics is…from an O'odham point of view; I think it's just physics, right?

Dylin's original perception of the relationship between culture and science was that science (or at least physics) exists *outside* of culture – not unlike Chang and Rosiek's (2003) description of "hegemonic thinking", the notion that science transcends culture. In this sense, his perspective of science was uncritical; he accepted Western science's narrative of acultural objectivity. Toward the end of the 2nd class, it looked as though the idea of perspective influencing science was starting to grow on him, as evidenced by this selection of the dialogue.

It would be fun to see, if we all picked the same topic, if we all do the same things…we come back, and that way we can kinda see our different results, why subjective or maybe not…That way we can check this whole, is it culture, you know; even though I'm part of this tribe, I wasn't always here…If we all go to get the same information…I guarantee you we're all gonna get different results.

From his description of how different students' perspectives could influence their conclusions about an activity, he was at least making space for the possibility that individual people could interpret a scientific investigation differently.

As described in the section on Velocity & Acceleration, during the 4th class in a discussion about constant velocity, Dylin made the connection between frames of reference in a physics sense (referring to observations depending on a frame of reference) to what we had talked about with interpretations depending on perspective. Also previously described in Velocity & Acceleration, he revisited the importance of perspective in the 5th session when deconstructing the meaning of "negative" velocity. What follows is the second half of that dialogue, in which Dylin examined the ways that physics uses a term that means something quite different in everyday speech.

Dylin:	So in theory can you not have a negative motion? It seems like, it's impossible to have a negative motion. It could have negative consequences [I laugh], but to have something moving, it always seems like it's positive…it seems like a positive type of energy, when you're moving something.
Me:	The negative in this sense only refers to direction…It's like left and right, east and west; it's just positive, negative.
Dylin:	So it's all relative.
Me:	Mmhm. It's relative to whatever sense that we decide.

Dylin was actively interpreting the scientific discourse relative to his own discourse to come to an understanding, in this case about what it means to have “negative” acceleration. This was an issue of different discourses using the same words to mean different things; as he pointed out, negative acceleration is not the same thing as something with “negative consequences”; physics and algebra use the term purely to refer to a direction. The context and perspective are essential for making sense of this double-dipping of vocabulary. He extended the connection he had made in the previous class between physical and cultural frames of reference, which in turn referred back to the discussion about perspective in the 2nd class.

Another way that Dylin’s perspective evolved was with regard to idealization. Perhaps because he had missed the first class and thus my initial speech about the book representing one perspective of physics, Dylin also took the book at face value. In the following excerpt from our 3rd class, as we were going over a homework assignment in which I asked the students to compare physics and science from the book’s perspective with their own perspective, Dylin expressed his straightforward analysis of the text. His synopsis aptly summarizes mainstream physics’ tendency to strip physical situations down to the fundamentals so that the interactions of interest can be examined without interference.

> What the part of the book was saying was you can’t get too ridiculous whenever you’re talking about [something]; it’s just too many factors to actually get a real answer, so you gotta break it down into more simple terms. Like it was talking about the baseball: you throw a baseball, each one weighs a little bit different, [its] design is a little bit different;

> you're talking about the wind speed and the Earth's pull and everything, and you take some little things out so you can actually get an answer to your question, because if you're calculating all that in, it gets too complicated. But you also don't take too many things out.

Two weeks later, however, he struggled to understand the concept of constant acceleration due to gravity because it didn't match up with his experiences in the real world (described in more detail in the section on Gravity), stating,

> I know it's probably true, because obviously, I mean, Newton and everyone doing this, obviously I'm not…even as close to as smart as [them], [but it] doesn't seem feasible.

Initially, Dylin started out comparing himself to famous scientists such as Newton and assessing himself as "not even as close to as smart". However, he had a question that the science was not addressing: if they're so smart, why did what they were describing not "seem feasible"? From his popular culture and experiential background knowledge, he knew that air resistance should be a factor, and it was being ignored in the physics story. When I said that the equations didn't account for air resistance, he finally felt empowered enough to challenge the science story and say, "but you have to." We then were able to critique the practice he described above, of breaking physical scenarios down into overly-simplified models. Dylin was expressing agency as he deferred to his own knowledge and asserted his (actually physically superior) understanding, which attempted to unify the effects on the falling object to create a more complete picture. Dylin's valuing of his own perspective and being critical of the textbook's take on reality empowered him as a contributor to the scientific discourse in the classroom.

Over the course of the class, pondering the issues of relativity and the implications for the credibility of science that he once took for granted, he concluded that all scientific simplifications are suspect. Dylin was particularly amenable to philosophical considerations, so it only took until the 5th class before he made the statement below.

Dylin:	I mean definitely, just comparing right now to the first day of class, [I have] a completely different perspective on science.
Me:	How so?
Dylin:	Because science is, it's not real. When I first came in I thought science, all this, that's the facts, that's the way it is, there's no doubt, that's how it's always gonna be, a hundred years from now we'll look back…And no, it's not. It's not really, you can prove or disprove pretty much anything.
Me:	Right. And in physics, what they call it is ideals, like 'the ideal frictionless surface,' 'the ideal machine that has perfect efficiency'. They don't exist in real life, but they create a model of these things so that they can analyze specific little things about it.
Dylin:	So what is the point?
Me:	The point is, well, in the minds of The Physicists, capital P that I just made up, the idea is to eliminate as much of the distractions of all the little trivial things that happen in real life, so they can look at what's really happening. You can get down to the basics. What are the things that are coming [into] play? What are the forces that are interacting? And then you can add in all the things, like there's the water vapor in the air, and there's air resistance, and there's

friction, and all this stuff; once you understand the basics, the most important motions, the most important forces, the most important interactions, then you can understand what's going on in real life when you add all those distractions in.

Dylin: Well isn't it fair to say then, right now we have these Newton laws, and a hundred years from now, they might not exist anymore, or they might be something completely different? Or a hundred years, two hundred years from now people will be like, 'back then they believed Newton's law, how stupid were they?!', that typa stuff. I mean isn't that theoretically possible?

Me: Absolutely.

Dylin had begun to eschew the value of the scientific Discourse due to its being overly removed from reality; his perspective had gone from uncritical to dismissive, suggesting that despite his readiness to consider a critical lens, he took the transition rather hard. We talked about why Western science takes this perspective of oversimplifying given its detachment from reality, and I did my best to characterize the motivations for doing so. The Western approach of reduction and dissection is in stark contrast to how a Native scientist might approach the same system, seeking to gain an understanding of the system as a whole and the role of each of its parts. Dyin rightly construed the Western approach of seeking fundamentals as a destabilizing force in scientific discourse, which can result in its changing over time. He may have found this notion even less satisfying, given his perspective at the start of the class.

Nevertheless, by the 8th class he was expressing his appreciation of the fact that Western science is *not* the absolute authority on the natural world. During a conversation in which we revisited our individual and course goals and whether we were meeting them, he summarized his position at that time:

> I really like what we're going over, and it makes my brain think and I like really thinking about these concepts and stuff, because some of these theories I don't agree with. Which is the best part about them, because they're not factual, they're not unfactual; they could change a hundred years from now, [or it] could be the same thing for the next one thousand years. And debating them I really like doing…I do go home and I see everything different for the next four hours…

Although perhaps his journey was a rude awakening to him at first, by the middle of the semester he had come to value his change in perspective. He had come to enjoy debating physics ideas, meaning that he had come to see himself as a scientific thinker, and that the world of science had room for him to be an expert too.

Conclusion

This course was designed to include a critical perspective of Western science, examining its assumptions and practices and deconstructing several ideas and assumptions implicit in scientific Discourse, such as the notion of "truth" and that science is "culture-free" and "objective". Examining the meanings of such terms as theory, which are different depending on who is using them and for what purpose, helped the students to develop a critical stance toward Western science and to develop views about science that were inclusive of the ways that different cultures construct knowledge about the natural world.

Drennan entered the course with a pre-existing love of and identification with science, and a desire to learn more about the natural world. Science was one element of his fluid identity, and he grew to understand that it should be part of everyone's identity, as part of each person's cultural heritage, no matter who they are. Drennan viewed everyone as natural scientists who owe our vast scientific knowledge resources to the collective efforts of our ancestors over time.

Dylin came into the classroom with the perspective that science is absolute and acultural, but quickly came to realize that complete objectivity is impossible. Once exposed to the notion of perspective influencing what a person sees about the world, he saw that this idea had both practical and philosophical implications. He was no longer able to see science (particularly Western science) as immutable and infallible, but this opened science up to him where he was able to see himself as playing a role in it.

Despite emphasizing different characteristics of science, both students developed perspectives that showed appreciation for its more subtle qualities, and more importantly, each came to know a face of science that had a space for his specific contributions.

Discussion

When it came to making connections between the students' interests and experiences and the class content, it wasn't necessary to ask the students to do this; they did it naturally whenever they had the chance. The students brought the connections between different realms of their lives into the shared classroom space with gusto, sharing such elements of their identities as the details of their home lives, the O'odham language and worldview, personal interests, pop culture references, what they knew already about other scientific ideas, and their questions and wonderings that were sparked in the moment. The students would have made these connections naturally on their own so long as they were engaged with the material, but these contributions to the class dialogue were more fruitful when voiced, where the class could explore them and possibly use them as building blocks to co-construct new knowledge and understandings.

Storytelling in the classroom was a means of building and demonstrating the students' conceptual understandings, and of making meaning through establishing connections between what the students were learning and what they knew and experienced outside the classroom. The beauty of this process was that all of this learning, all the sparking of neurons and making connections, was completely imbedded in the things that the students were already interested in – by its nature, it was relevant and meaningful to them.

The students' connections between course content and other topics can be categorized as cultural connections, personal connections, and philosophical considerations. These categories are summarized in turn below.

Cultural Connections

The ability to draw cultural connections into the classroom was not something I felt confident that I would be able to support when I began planning and teaching this course, so the "culture" part of cultural relevance fell heavily to the students, as well as to other participants in the class. The students and the class' cultural advisor did a beautiful job of incorporating the culture into discussions, in both expected and surprising ways. Cultural connections included the students', particularly Drennan's, incorporation of the O'odham language (which had been a goal presented to me by the Himdag Committee) and both students' expressions of cultural values. In addition, the two topics selected by the cultural advisor and me especially for their cultural relevance, the atlatl and heat, were also avenues for making cultural connections – especially for Drennan with the former, and Dylin with the latter.

For both students, the cultural connections they brought in were ways for them to incorporate their out-of-class identities and to consider their cultures from a scientific perspective. Not only were they important for helping to make physical concepts meaningful in a cultural context, they were also motivating for the students. Drennan put this idea in his own words during my interview with him after the end of the semester, elaborating on how a cultural focus promotes students' learning.

Me:	How does…including cultural elements affect students'…learning?
Drennan:	Well, personally I think it helped…you understand a little more, 'cause…when someone learns something that's personal to them, or like has something specific for them…they actually wanna learn more, like "oh I didn't know that." It broadens their horizons; they wanna just learn more and more. And I think the cultural thing was a pretty good idea. It, if someone just said "come to physics class," you'd "oh, man! Really?" [with a being-dragged-against-your-will tone of voice] They're like, "It's having to do with culture." "Cool!" You know?

As Drennan's words suggest, physics itself may not be students' most sought-after topic to study, but physics from a cultural perspective, and likely any science with a cultural perspective, is a much more interesting prospect. The cultural connections brought in by the students allowed them to consider themselves as cultural beings within the realm of science and seek out the meaning of the content they were learning from within that identity. They also allowed them to examine the role of scientific knowledge within the community.

Personal Connections

The category of personal connections, arising from students' personal interests, hobbies, and experiences, emerged as distinct from the cultural connections category, derived from the shared context with the students' community. However, the line between what is personal and what is cultural is blurry at best. Because cultural connections are not necessarily equivalent to "traditional O'odham connections," it was possible that the cultural influences identified came from "secular" sources such as literature, movies, and television, rather than from the O'odham traditions. In any case, these secular resources were critical for the students as they interpreted and attached meaning to physical concepts.

Moje et al. (2004) found that popular culture funds of knowledge were especially prominent relative to other funds, and that students incorporated popular culture funds of knowledge as much or more than their own experiences in their science discourse. Because Drennan and Dylin were adults, invested with autonomy and a great deal of life experience, their access to different discourses and funds of knowledge was extensive, and their identities as individuals were as salient as their identities as members of the Tohono O'odham Nation. As a result, the influence of their personal connections on the co-constructed third space was just as important as that of the cultural connections. Both students drove, watched television, and went to see movies, so they possessed popular culture and experiential funds of knowledge related to science. Naturally, because each student was unique, each also brought his own individual interests. Dylin was, among other things, a fan of Star Wars science fiction literature and a former football player. Dylin's interest in watching and playing football served as a useful context for him as he was learning about concepts such as position, velocity, momentum, and impulse.

Some of Drennan's interests were supernatural (or pseudoscience, depending on how you look at it) topics such as psychic energy and aliens; he also enjoyed watching History and Science channel specials. Drennan drew upon his interests and existing scientific knowledge in learning about concepts such as gravity and energy.

The shared classroom context was also a valuable resource in the classroom, because as we spent more time together as a community, albeit a very small community, this resource continued to grow. Being able to connect to this shared fund of knowledge gave us the sense that we were building something that was unique to our specific collective – a hybrid discourse that would not be the same anywhere or with anyone else. Thus, such elements as the recurring topic of explosions were important, despite their limited applicability to the course content.

Philosophical Considerations of Physical Concepts

Both students both enjoyed taking physical ideas and running with them, examining their philosophical and spiritual implications. These philosophical considerations emerged from the students' dialogues about velocity and frames of reference, the atlatl and the collapse of civilization, Newton's 3rd law of motion and the role of conflict, energy and the central importance of life, and the cultural and evolving nature of science itself. These dialogues provided windows into students' thinking that would not have been accessible in other ways. As the instructor, I had to let go of what I wanted to say and what I thought we should be doing in order to truly hear what the students had to say. And what they had to say was brilliant, reaching to the far corners of human knowledge to explore the implications of the subject we were learning. In these moments, everyone in the class was on a level playing field, and real authentic learning was taking place, because it was what the students wanted to know and wanted to think about, not just what the curriculum or I told them they needed to learn.

Conclusions

What especially stood out about this class and the way these students interacted with it was the high degree of personal relevance. Increasing the personal relevance of curricula is a best practice in adult learning theory (Knowles, 1973), and there is a great deal of overlap between what is personal and what is cultural, as personal experiences are interpreted through a cultural lens. In the beginning, I was overly focused on O'odham connections as cultural connections, and while these connections were there (inclusion of the language, elements of the Himdag, explorations with the atlatl, traditional storytelling), they were certainly not the most prominent type of connection being made. But culture is more than just what can be cleanly categorized as “O’odham”; that which is cultural is inclusive of not only traditional but modern O’odham language, backgrounds, experiences, interests, and values. This being the case, it is impossible to truly separate the categories of cultural, personal and philosophical connections.

While teaching the course, the Socratic-style dialogues were the evidence I was looking for that the culturally-relevant pedagogy was a success: The students had voiced that they wanted a verbally-oriented curriculum and assessment structure, and the fact that they could succeed in this structure, as evidenced by the conceptual understanding they demonstrated in oral exams and informal dialogues, meant that the course as a whole had succeeded. However, when the students took control of the dialogues and mulled over the content and its implications, the whole class learned from the conversations that resulted. It wasn’t until the fateful 10th class dialogues, that turning point in the semester, when I realized there was more to it than that. When I was directing the dialogues, I was looking for students’ competence, yes, but their competence as measured by the learning objectives of the course. When they were directing the dialogues, they were demonstrating their competence with the other principles of cultural relevance as defined by Ladson-Billings (1995a, b): maintaining their cultural integrity, in this case acknowledging their cultural scientific heritage, and developing a critical perspective, in this case with regard to the field of science. In sum, what the students learned was what they chose to take from the course content, which was based upon what they chose to bring into the classroom and what meanings they were able to assign from their pre-existing interests and values.

CHAPTER 5: FINDINGS & CONCLUSIONS

Introduction

Dialogues with the students in this classroom may have appeared to an outside party to be exercises in group free association. However, allowing students free reign to make connections – with their culture, with their interests, with their personal lives – and empowering them to make decisions about their own learning – including what to learn, how to learn, and how to assess that learning – were all means of encouraging students to develop meaningful conceptual understanding. The third space created in the classroom by the students and instructor gave voice to the struggle to build these conceptual understandings, and space to ponder the implications in the group setting.

In this chapter, I present this study's findings and their relationship to the research literature, followed by the limitations and the implications for others doing work in this field. Finally, I present areas for future research and a discussion of the conclusions of the study.

Summary of Findings

Finding #1: Dialogical interactions were the students preferred means of developing understandings and attaching to meaning to physical concepts.

The informal, verbal communication-oriented classroom environment provided the space for the students to explore physical content through dialogue; along with hands-on experiences and readings from the text, the students had a multi-faceted exposure to ideas and they used dialogues to seek connections between these class-sanctioned activities and their prior knowledge and experiences. Interactive lectures and open-ended discussions provided ample opportunities for the students to invent imagined scenarios, relate stories, pose questions, and create metaphors related to physical concepts.

Students need opportunities to explore the content from their own perspectives, to negotiate their own meanings within a safe third space where they can bring their identities. The students who participated in this research mirrored those described by Cajete (1999b), in that they preferred a more informal learning environment, as well as having an "oral as opposed to a written language orientation". Like the students described by Aragon (2002), they sought out opportunities to engage and collaborate, with me and with each other, using the content as the medium. The fact that the students in this study were comfortable sharing their identities and funds of knowledge in the classroom suggests that space was created for these connections, per Moje et al.'s (2004) recommendations. That the environment was also characterized by being driven by student interest and sharing authority among the classroom participants reflects Patchen and Cox-Petersen's (2008) finding that these characteristics are key elements for creating a culturally responsive classroom.

Finding #2: The student participants created meaning around physical concepts through connections to their cultural and personal funds of knowledge.

Each topic in the introductory physics curriculum, from the most familiar (velocity, gravity) to the most obscure (hydraulics, thermodynamics) became a site for meaning making through connections to students' funds of knowledge. The students themselves made these connections to their funds of knowledge from their personal and cultural identities (Vélez-Ibáñez & Greenberg, 1992; Cajete, 1988), such as Dylin's car accident serving as a reference point for velocity, momentum, and impulse, and Drennan's interest in astronomy serving as a context for momentum, gravity, and energy. This supports the research of Moje et al. (2004) with elementary school children, who had significant funds of knowledge that they applied to learning physics. The fact that popular culture funds of knowledge were particularly salient to the students in this study (e.g. from their familiarity with science fiction and popular science) also support Moje et al.'s finding that popular culture funds of knowledge were as relevant to the student participants as their own personal experiences.

As Cajete (1999b) described of his students, the student participants in this research related their learning to "a familiar set of descriptive relationships". Sometimes these descriptive relationships came from the popular culture, as described above, and sometimes they came from the O'odham culture, such as Drennan's use of the O'odham language to interpret velocity, Dylin's identification of scientific knowledge in the O'odham story about the weather, and the way the students thought about life and energy. The students' meaning-making processes reflected Wilson's (2008) method of developing understandings by forming relationships between oneself and that which one is trying to understand. Wilson related this notion to research, but it is also a metaphor for what students were doing to learn about science content. The cultural connections were essential because the culture comprised an identity that the students shared with others – most notably in this case, with each other. Likewise, the connections drawn from the shared classroom context, such as the references to explosions, reflected our identities as members of the class. The personal connections derived from pop culture and students' particular interests were equally essential, because they derived from the students' identities as individuals.

Students embrace different aspects of their identities as they navigate their worlds; they are simultaneously sons and daughters, tribal members, members of the student body, future professionals, parents, academics, athletes, and music-lovers. The funds of knowledge they connect with their learning at any given moment depends on the context. While these students were O'odham, they were also individuals with personal interests and activities, and these things also influenced their lives and personalities, which were drawn out in the third space.

Finding #3: The student participants created meaning around physical concepts through the pursuit of philosophical considerations.

Emotional, intuitive, and moral considerations were part of the meaning-making process for the students, such as when Dylin related frames of reference to the influence of perspective on interpretations, and when Drennan related mass and gravity to the evolution of life. The students were not merely interested in learning about physical concepts because they were interesting in their own right (explosions notwithstanding), but because they had a purpose for the students' lives. Dylin took a personal interest in applying physical principles toward determining the safety of a vehicle; Drennan related physics back to the experiential and sought connections between physics and all forms of life. The broader considerations about the implications of physical knowledge were more important than the knowledge itself; as Cajete (1999a) opined, spirituality gives meaning to learning. Philosophical considerations allowed the students to express their creativity, to create meaning around questions that they cared about, and to seek out the implications of physical ideas.

This finding supports the theories of Pewewardy (2001), Simonelli (1994), and Dyck (2001), who included the spiritual and the emotional as contributing to Indigenous science, as much as the mental and the physical. As well, Balgopal, Wallace and Dahlberg (2012) and Wickman and Östman (2002) both wrote about emotions affecting learning, among students from any cultural group.

Finding #4: Students made meaning through storytelling in the classroom dialogues.

Stories are a traditional method of communicating knowledge and values in tribal communities (Campbell, 1991; Van Hamme, 1996). Dylin frequently told stories that synopsized plotlines from Star Wars novels, popular science documentaries, and movies; his stories often served as metaphors for the scientific content of the class, such as his story about putting up communication towers in the galaxy relating to sending information across a distance (fields). Drennan often included stories from his personal experiences that he would then interpret using his new physics knowledge, such as his story about the plasma ball (phases of matter) and the story from his journal about being in a car with a reckless driver (momentum). The stories told by the students were a means of providing context for physical interactions, and they also held personal meaning for the storytellers. The dialogues involving multiple contributors, which was the majority of the dialogues but most notably those constructing class understandings of Newton’s third law and energy, could be looked at as following the Talking Circle format described by Running Wolf and Rickard (2003), in which multiple viewpoints are heard and respected.

This finding supports Snively and Corsiglia's (1998) description of how Native peoples used stories to communicate scientific information, as well as Zepeda's (2001) narrative about the O'odham hunters' taxonomic knowledge. Stories were a natural way for the students to personalize their understandings of the content, as well as to share their understandings with the other members of the class. These stories were certainly not always arising from "traditional O'odham culture", as evidenced by, for instance, Dylin's stories about Star Wars and Drennan's stories about modern life on the reservation, but the pattern of using stories may reflect a traditional pedagogical method of teaching and learning.

Finding #5: The students made meanings of the nature of science that meshed with their identities and created a space for them to identify as scientists.

Throughout the semester, Western science was viewed through a critical lens that challenged its dominance in modern culture. Part of this was an effort to build students' *metadiscursive awareness* (Moje et al., 2001) by unpacking the language of science Discourse, hence demystifying it. Deconstructing and challenging the practices and assumptions of Western science, such as how it reduces scenarios to bare interactions by stripping away the context, mitigated potential assimilative outcomes of clashes between students' knowledge and Western scientific knowledge. Maintaining a critical stance toward Western science contributed to the classroom environment by inviting students to be skeptical rather than asking them to throw out their prior knowledge and beliefs; instead, they were invited to compare and contrast their own perspectives with the course content offered by the text. This was related to what Snively (1986), Cajete (1999a, 1999b), and Hermes (2000) discussed about how different science epistemologies from different cultural perspectives can be taught side by side to show their similarities and differences, and to show how together they create a more complete picture.

Through critically evaluating the scientific narrative, the students' interpretations of science evolved; Drennan's view of science became even more inclusive, Dylin's became less rigid, and both students' views became more critical. Drennan came to see science as a natural outcome of human curiosity, yet found that science is unable to address the "why" of physical phenomena nor to address human interpretation of these phenomena; this left space for the expression of his identity as a science lover and expert among his peers, but also the other facets of his identity unrelated to science. Dylin found that science is not the ultimate authority, but rather is dependent upon perspective and open for debate; this gave space for him to question the scientific narrative.

The students' experiences were in contrast to those of science students such as Curran (1995), who was told she could not be a scientist and remain culturally grounded; the students in Brown's study (2006), who did not see themselves as part of a community of scientists but rather projected scientific ideas onto Others; the authoritative Discourse of science requiring the abandonment of parts of their identities to embrace; and Brandt's (2008b) Navajo college student participant who had to compartmentalize scientific and cultural teachings in order to move forward, deferring to science's credibility but maintaining belief in her traditional stories.

The students shared authority with the science content, such as Dylin's challenge of constant acceleration due to gravity, and Drennan's insistence that energy could only be defined in context. Sharing authority was recommended as one of Engle and Conant's (2002) principles for fostering engagement with academic content. This is similar to Gilbert John's (2001) message to students, that they will be more successful if they seek the overlap between science and their cultures, as he did; it also suggests that the students fell into Benjamin, Chambers and Reiterman's (1993) "persisters" category and Gallagher's (2000) more successful college students, as they maintained their cultural identities but were also comfortable with the mainstream narrative.

As Calabrese Barton, Tan and Rivet (2008) discussed, the third space integrated the students' identities and the scientific Discourse, and the boundaries between the two became less rigid, echoing both what Lipka et al. (2005) described in their research and Brandt's (2008a) *locations of possibility*. As Tippins (in Brandt, 2008a) related, settings such as our classroom provide possibilities for students to examine different narratives about the natural world, to tell their own stories, to value their traditional stories, and to embrace the pluralism in ways of understanding the world.

Finding #6: Both students made meanings of science that viewed science as part of their cultural heritage.

Science was presented in our class as a culturally-grounded practice that emerges from the way that cultures interpret the world. All cultures have their own means of obtaining information about the world that helps them to survive in their environment (Cajete, 1999a), and the students' traditional culture is no different. Western science was recognized as one culture's approach to, and understanding of, the natural world (Zacharias & Calabrese-Barton, 2003), with its dominance a non-neutral consequence of societal influences. This philosophy contributed to the inclusiveness of the class by leveling the playing field for alternate interpretations of the physical world and encouraging students to take pride in the knowledge that their community had developed. Drennan referred to the atlatl as an example of his ancestors' ingenuity, sparking his curiosity about other innovations his ancestors had developed and linking to his knowledge of ways that modern O'odham use and thrive in the desert. Dylin located scientific knowledge in his culture's story about the seasons and recognized that this place-based knowledge was sophisticated.

Researchers Brickhouse, Lowery and Schultz (2000); Brown (2006); and Calabrese Barton, Tan and Rivet (2008) posited that learning science requires identifying with a scientific community. For these students, this identification involved coming to understand that their tribal community is a scientific community of practice. As Barnhardt (in Brandt, 2008a) suggested, learning about both Western and O'odham science together allowed for a deeper understanding of both and supported students' identities in the process.

Finding #7: The class as a group created hybrid understandings of Newton's 3rd law of motion and energy through dialogues that took place in the third space.

Moje et al (2004) described third spaces as spaces where disparate ideas and perspectives can work together to yield new knowledge. Conflict, such as that described in the Newton's 3rd law dialogue and enacted in the energy dialogue, is the impetus for new growth; tension was described by Gutiérrez et al. (1995) as being that which both creates and maintains the third space – thus tension is essential for developing hybrid understandings. Thus, our diversity of personalities, backgrounds and value systems was a resource in the third space, and led to the development of new ideas, as evidenced in these two key dialogues.

The Newton's 3rd law dialogue showed evidence of a holistic worldview, while the energy dialogue showed evidence of a pluralistic worldview (Aikenhead & Jegede, 1999). In the former, different knowledges come together to create a unified whole; the Newton's third law discussion did this by approaching the notion of forces in balance from different perspectives and creating multiple contexts where this notion could come into play. The Newton's third law discussion engaged a holistic worldview by drawing out the abstract from the Western science narrative and employing it in a life-centered context from the tribal perspective and a philosophical, moral perspective. Approaching this counter-intuitive physical principle from multiple angles in a discussion to which all members of the class contributed led to a highly nuanced picture of the third law.

In a pluralistic worldview, different perspectives are juxtaposed but remain distinct; the energy dialogue introduced multiple views of energy, though they did not merge into one blended perspective. The students' perspective of energy as life and life as the purpose of the Universe were in contrast to my perspective of life as separate from energy and life as a local phenomenon. As Cajete (1999b) discussed, it was not necessarily a problem for the students to contend with such disparate ideas, if they are aware of, and have resolved to their own satisfaction, any conflicts among them. The energy dialogue reflected Ogawa's (1995) notion of multiscience teaching, where different sciences (i.e. indigenous, personal, and Western) are explicitly compared, and

Ogunniyi's (1988) conclusions that students can understand scientific phenomena in different ways and can choose from among them. The tension between the ideas can, as Mortimer and Scott (2003) suggested, be key opportunities for meaning making to occur; the energy dialogue required all class members to put their ideas about energy into words and justify them. Even though we were unable to come to a consensus, Mortimer and Scott, along with Aguiar, Mortimer and Scott (2010), would argue that this dialogic process was meaning making in progress. This meaning making was built not only upon our hybridity (the existence of diverse perspectives) but also upon the ability to voice those perspectives in a third space (a respectful environment where myriad viewpoints are welcomed and equally respected), echoing Gutiérrez, Rymes and Larson (1995).

Finding #8: The students' meaning making around the physical concept of energy flowed from an understanding of energy as life, and life as the central purpose of the Universe.

The students held a worldview linking energy, life and spirit that was quite foreign to me when we began the semester. The students' understanding of life as the central function of the Universe and humans as powerful co-creators of the natural world was reflected not only in the co-constructed dialogue about life and energy but also in both students' comments about the function of ceremonies and the abilities of the human body. This perspective was also affirmed by Cajete (2008), who said, "Humans are co-creators with the higher powers of nature so that everything that we do has importance for the rest of the world" (p. 491). As a physics instructor purporting to teach students about "the systems that organize the universe", this was one system I clearly missed.

Without the students' intervention, this perspective would not have been a part of the third space, and even when it was it must be said that my reaction to it was almost hostile. According to Jones and Jenkins (2008), even with good intentions the dominant group's ability to hear the marginalized voices is compromised by their lack of ability to relate to these groups' experiences (in fact, the deafness to these voices is, they stated (p. 478), "one of the necessary conditions of a colonized society"). My inability to grasp this perspective handicapped the respectful flow of ideas in the third space, and was a missed opportunity for collaborative meaning making around the idea of life at the center of the Universe and hence the central focus of physics.

Finding #9: Context was essential for students' meaning making about certain physical concepts.

For the students, certain physical concepts did not make sense without the context into which to situate them. Drennan made this point when attempting to define energy and power; because of their ubiquity, energy and power only become "visible" in a scenario when you can see their effects, and their effects are specific to the scenario. Dylin made a similar point when he took issue with the notion of constant velocity and constant acceleration due to gravity; these values are only "constant" in certain frames of reference (in the former case) or in the absence of other variables (in the latter). The students' difficulty with the absence of context challenged my expectation as the instructor that we were confronting physical misconceptions; this was not the case. The abstract concepts themselves – energy, gravity, velocity, acceleration – were not as troubling to the students as was the way in which the concepts were presented. This is critical information for a physics instructor, or any science instructor to be aware of; Western science's predilection for "ideal" cases strips the concepts of their meaning for this population of students, making them potentially incomprehensible.

The importance of context is one of the values of Indigenous methodologies (Tafoya, 1995; Wilson, 2008). Nothing exists in isolation; all things exist within a complex series of interrelationships with all other things, or what Wilson referred to as a "knot". The conflict between holistic and reductionist viewpoints is a potential conflict for some Native learners; simplified models do not make sense if they do not match the relational nature of reality.

Finding #10: Each student used different meaning-making strategies, despite being from the same cultural backgrounds.

In every case, Drennan's and Dylin's approaches to learning about each physical concept was tailored to him, drawing upon his specific funds of knowledge from his experiences, cultural traditions, personal interests, academic background, prior content knowledge, and any and all other resources available to him. For Drennan, the O'odham language was a fund of knowledge from which he could draw; for Dylin it was not. For Dylin, the O'odham values were more salient, and he was able to identify which were specifically O'odham because he had lived in a mainstream setting; for Drennan the O'odham values permeated his whole life. Every student who enters a classroom is an individual and will connect with the content in his or her own way. Even at tribal colleges, students do not all enter the classroom with the same cultural funds of knowledge, nor can they be expected to reflect cultural values to the same degree.

As this highly diverse class of two students suggests, one-size-fits-all curricula, even those designed with cultural relevance in mind, will not appeal equally to the diversity of students that exists in even very small populations. Cultural relevance means more than just bringing in cultural artifacts or the language; it requires making space for the students as cultural beings, where culture includes not only traditional historical characteristics of the group but also modern interpretations of tribal identity of every flavor. This approach contrasts with the troubling paradigm identified by Hermes (2000) in which “cultural” and “academic” curricula are superimposed upon each other, instead of allowing the two to blend in the third space; the latter approach results in essentializing the culture and positioning it as seemingly anti-intellectual.

Finding #11: The meanings co-constructed by the members of the class in the third space were a valuable tool for enhancing the cultural relevance of the course.

Each connection made by a student, or even occasionally by me as the instructor, was a bridge to the culture (Belgarde, Mitchell & Arquero, 2002). It is impossible to draw clear lines around what is “cultural” versus what is purely “personal”, though there were funds of knowledge that the students themselves identified as cultural, such as Drennan’s references to the way the O’odham people use the desert, and those that can more easily be considered non-O’odham, such as the Star Wars novels and Carl Sagan specials. Nevertheless, students interpreted the latter experiences through their cultural identities, and even mundane experiences like driving a car and riding on a Ferris wheel can be understood from within a shared cultural framework (e.g. driving on the long roads of the Tohono O’odham Nation, or riding a Ferris wheel at the Tohono O’odham Nation Rodeo

& Fair). The lines between what is "personal", "cultural" and "philosophical" are nebulous and possibly non-existent; as Hermes (2000, p. 395) wrote, students should be "supported to bring all of their experiences" into the classroom, and not encouraged to separate their cultural identities from their holistic identities.

The blending of hybrid dialogues in the third space addressed Ladson-Billings' (1995a) three criteria of culturally relevant curricula by supporting students in developing conceptual understanding of the content, including the scientific knowledge imbedded in cultural traditions, and involving the students in critical analysis of the claims and assumptions of Western science. The critical, social-justice oriented perspectives incorporated into the hybrid dialogues also resonate with Curtis' (1998) call for critical pedagogy in culturally-relevant curricula. The notion of the construction of third space reveals the opportunities that exist in intercultural classrooms, because it frames cultural difference as an opportunity for the co-construction of knowledge in uncharted grounds, such as the learning of physics.

Limitations

There are several limitations to this study that affect its validity and generalizability. The most immediately apparent is the very small sample size of two students, which limited the generalizability in several ways. For one, because the sample was so small – two students and one instructor, at one tribal college, imbedded within one tribal community – the results of this study cannot be generalized beyond this classroom. However, it was also not intended to be.

The small class size also meant that the opportunity to include and build upon student input was quite a bit greater than it would have been in a larger class; not only was the class small enough for every voice to be heard, I also had extended lengths of one-on-one time with each student that influenced our relationships, as well as the students' learning. In a larger class, the diversity of perspectives in the third space would have been greater, but the opportunity for each student's ideas and opinions to be expressed would have been limited. In addition, the relationships among a larger body of students may have resulted in a very different power dynamic, which would influence the hybrid dialogue in unknown ways.

The identities of individuals strongly influenced the dialogic interactions. The demographics of the class were very specific: one female instructor, two male students, all similar ages; two O'odham students, one with a more traditional upbringing and one raised primarily off the reservation, and their non-Native instructor. With a different set of individuals, the results presumably would have been quite different.

Though my intentions from the beginning were to foster what I would now consider to be a "third space" in the classroom, it was not my explicit intention to create hybrid understandings; these theoretical constructs were applied to the interpretation of the data nearly two years after the conclusion of the course. If I had intentionally structured the course to foster the development of hybrid understandings of concepts, the possibilities for hybridization may have been more extensive; as it was, hybridization only occurred by chance as a consequence of a tenuously-understood combination of variables. Moje et al. (2004) suggested that there may be commonalities among teachers who explicitly strive to create third spaces in their classrooms, but that opportunities to capitalize on students' funds of knowledge can be missed by those who do not.

As a non-Native instructor, my interpretation of students' thinking, learning, and contributions to the dialogue are different from a Native, and more specifically O'odham, instructor. As an outsider to the culture of my students, I no doubt missed nuances and layers of meaning in students' ideas, as well as opportunities to draw in cultural connections that would have been available to instructors with more cultural capital. In addition, instructors with connections to the larger community may have been able to extend the classroom to the surrounding areas and bring in expertise from other community members, which would have broadened the scope of the third space.

Further limitations exist for the methods undertaken to analyze the data. The most egregious of these is the fact that I did not have the participants weigh in on the analysis, despite my intentions to do so. The students received copies of the raw data, but this was far from the form in which it is now, but in the years between the completion of the course and transcription process, and the completion of the data analysis, the participants and I have lost touch, and our ability to communicate across different states and modes of communication has been limited. Having the participants – students and others – take part in the analysis process would have resulted in a richer, more authentic final product that reflected not only my interpretations but the participants' interpretations as well. This would have been another opportunity for productive negotiations in the third space.

Implications

One of Atkinson's (2001) principles for Indigenous research pertained to purposeful action. What actions might my research spur? Will it lead to more effective educational experiences for O'odham students? Will it lead to increased pride and confidence amongst the students about their own capabilities? Will it lead instructors to consider new ways of engaging their students' intellects in the classroom? In this section I consider the implications for this study, especially as a potential agent of change.

For those who administer tribal colleges and supervise faculty, the findings of this study suggests that autonomy and flexibility are important for the development of courses that are responsive to students' needs and preferences. This study reveals that students take ownership of the course and their role in it when they are invited to co-create its structure and syllabus, and to make changes if necessary along the way. Co-creation is unpredictable, and courses will not likely follow the same procedures from one semester to another, or from one instructor to another. Courses may diverge from the stated learning objectives, and outcomes may be quite different depending on which topics the students in the class choose to emphasize. Maintaining the quality of these courses while allowing for flexibility requires support and professional development of the faculty.

For tribal college instructors and other Native educators, this study tells us that open classroom discourse is an avenue toward cultural relevance and a viable strategy for promoting meaningful student learning. Through the voicing of their hopes and concerns for their learning, as well as the connections between their funds of knowledge and the content, students actively construct conceptual understandings that are rooted in the richness of their cultural and personal backgrounds. In larger and more lecture-oriented classes, student connections from their cultural and personal funds of knowledge can be fostered through small-group discussions or reflective writing. By negotiating meanings among the students and in collaboration with others in the classroom community (e.g. parents, elders, subject professionals), students can not only learn about content but create new interpretations of it; these interpretations can be shared more broadly through student presentations and publications for the campus community and beyond. If students are supported in developing their own interpretations of content, critically analyzing the dominant narrative, and seeking out their own ancestral knowledge imbedded in their cultural traditions, their pride and ownership of the material may serve as motivators for their current and future academic endeavors.

Finally, for educational researcher, the study findings imply that there is meaning in classroom dialogues, and that we can seek evidence of student learning even in conversations and utterances that appear to be off-topic; a closer look may reveal that students are speaking metaphorically, are exploring a tentative connection in another realm of thought, or are testing the boundaries of their authority in the third space. Although there is value in examining student speech around the content area, there is also value in examining the ways that students process their learning in the less academic dialogical spaces.

Future work

Future research in tribal college classrooms can examine the learning outcomes for students taught in a learning environment that supports hybrid dialogues to see if the link between the third space and the development of conceptual understanding is as concrete as this study suggests. Further studies are also necessary for investigating potential benefits and detriments of this teaching approach on not only students' knowledge outcomes but also their skills, attitudes, and self-efficacy in science.

The challenge for applying this model of third space is to validate it for interactions among a higher number of students. If the model can be shown to have value for other classes and to be applicable by other faculty members, non-Native instructors of science may find another means of offering not just content to their tribal college students, but also cultural relevance. If, as Drennan commented in his post-semester interview, there is no subject area for which the approach we used is inappropriate, future studies can also research the possibilities for third space construction and cultural integration for classes in fields beyond science. Future research can attempt this curricular approach in multidisciplinary classes, like linked learning communities of, for instance, science and the humanities. Such research would be in keeping with the recommendations of Cajete (1999a) and Kawagley, Norris-Tull and Norris-Tull (1995), who emphasized the importance of a curriculum that " integrates the natural sciences with social sciences, language arts, humanities, and mathematics in a way which the learner can recognize as having legitimate meaning in daily life" (p. 7).

As well, while this classroom included a multicultural element because of the difference between the students' and my cultures, hybridity is still present in classrooms where the instructor and students are of the same culture when students have the opportunity to voice their perspectives alongside the academic discourse. Thus, future research can examine the dialogues that emerge in monocultural classrooms and compare them with the results of this study; there are potentially useful and interesting lessons to be learned from the similarities and differences between the third spaces that arise in these two types of classroom, which may pertain to the decisions instructors make as they respond to each class' demographic.

In this study, both students expressed a preference for learning through dialogue. For students who are less apt to express themselves verbally, how can the third space be shaped to include them? Future research can explore how writing, art and/or performance can be avenues for students to express the connections between their funds of knowledge and the classroom content. Technology could be used to simulate discussions, for instance through synchronous and asynchronous discussion capabilities that are often imbedded into online course management tools. In this manner, classmates who do not share a physical space can still co-construct a third space. Further studies can explore how these virtual third spaces compare to dialogical third spaces occurring in the classroom in real-time.

Conclusions

The results of this research paint a picture of student ownership of their learning, where students help to construct the learning environment by providing their voices. Students' meaning making within the classroom community drew upon their goals for being at the college, their goals for taking this course, their personal interest (or lack thereof) in the subject matter, the connections they made between the content and other areas of their lives, and what they considered to be the importance and implications of what they were learning.

This research also depicts the development of a community of learners, consisting of both the students and myself on a journey of mutual and conceptual understanding. The personal connections that students brought into the classroom helped make physical concepts real for them, rather than highly abstract concepts they read about in a textbook. The students used these personal connections to link the content to their own identities, where they took ownership of this learning and used it to enrich their understandings of the worlds they had constructed for themselves. Meanwhile, I was undergoing a process of meaning making myself, as I attempted to make sense of the importance of the learning processes and understandings that the students engaged throughout class.

Jones and Jenkins (2008) cited Bhabha (1994) and Spivak (1988) in warning about the invitation to dialogue by the dominant group to the marginalized group as a potential trap for the marginalized group, an opening up of their experiences for the voyeurism of the dominant group. Despite my best intentions, it is possible that my efforts to share power with the students in the classroom only reinforced the power differential. “It is the colonizer, wishing to hear, who calls for dialogue” (Jones & Jenkins, 2008, p. 478). In other words, the colonizer *gives* the power to the marginalized and *allows* for the oppressed groups’ voices to be heard; the imbalance of power clearly remains. As a White instructor in my classroom, I was exercising my power – as their instructor, primarily, but also as a member of the dominant society – in “giving” them voice, or rather, as I have come to think of it, creating a space where their voices were welcome. I have presented the results of the analysis with this warning in mind, but it is still possible that I have overlooked a colonizing influence in my work. It is important to note that what I have presented is not the reality of the classroom as the students understood it, but my interpretation of the students' understandings.

Kathy Absolon, Indigenous researcher and educator (in Kovach, 2009), said, "At a structural level, one of the roles of the educator is to bring validation and help widen the path for other Aboriginal people to be okay with who they are. To know that if you choose the path of education you can still come in and be who you are" (p. 150). Although Absolon's words reflect her identity as an Indigenous researcher and educator, welcoming other Indigenous scholars into the fold, this quote also represents my goals as an educator and with this research in particular: to show that my students' identities, whatever they may be, are enough; they don't need to change to learn something so strongly associated with a Western perspective. We can build bridges and learn from each other without undermining our identities. Bishop (2008, p. 446) summarized Cook-Sather's (2002) research, stating,

> [S]uch authorizing of students' experiences and understandings can directly improve educational practice in that when teachers listen to and learn from students, they can begin to see the world from the perspective of those students. This, in turn, can help teachers make what they teach more accessible to students. These actions can also contribute to the conceptualization of teaching, learning, and the ways we study as being more collaborative processes. Furthermore, students can feel empowered when they are taken seriously and attended to as knowledgeable participants in learning conversations,

> and they can be motivated to participate constructively in their education. In addition, [Cook-Sather] further identifies that authorizing students' perspectives is a major way of addressing power imbalances in classrooms in order for students' voices to have legitimacy in the learning setting.

Coincidentally or not, this summarizes the goals of this research to a tee.

Nevertheless, overemphasis on the ways that our identities blend together, thereby ignoring ways in which our identities diverge, can result in our blending into one homogenous mass (most frequently the image of the dominant people). McLaren (1997) stated that "care must be taken not to equate hybridity with equality" (p. 537), and Fusco (1995) wrote, "The postcolonial celebration of hybridity has (too often) been interpreted as the sign that no further concern about the politics of representation and cultural exchange is needed" (in McLaren, 1997, p. 46). Others expressing this concern are Giroux (1992), Grande (2008), Jones and Jenkins (2008), McCarthy (1995), Mohanty (1991), and Ogbu (1978). Just because we can come to collective understandings by scaffolding from individual understandings, does not mean that the individual understandings cease to be important. Without a diversity of understandings, a diversity of perspectives and philosophies and intentions, such new creations could not be built. Honoring difference remains a critical goal.

The separation of the results by physics content area is an artifice of the analysis. In reality, as the accounting of when the dialogues took place reveal, the integrated nature of the different physical concepts and the organic nature of the course dialogues resulted in multiple instances of exploration of each concept across time. The reality of these explorations was that they spiraled outward from the abstract concepts, incorporating other physical concepts and non-physical ideas as the students became more familiar with them; the analysis reduced these spirals to a linear process. As Brayboy and Deyhle (2008) lamented, “We believe we are hampered in many ways by having to write and analyze within categories. We believe in a holistic view of research and analysis that connects as many different ideas and strands as necessary for a complete analysis. Breaking the analysis into distinct parts feels disjointed and severe” (p. 168). Similar messages have come from many different scholars in Indigenous research (e.g. Wilson, 2008; Kenny, 2000; Kovach, 2009). I agree with this; it is very difficult to compartmentalize lived experience this way. I too believe that connection is more important than separation – that is, that synthesis is more important than analysis.

Indigenous scholar Lewis Cardinal stated, “We are all looking for that deeper sense of meaning, that great quest for the meaning of life, that connection to something bigger than yourself” (in Wilson, 2008, p. 94). Learning about physics serves precisely this purpose, to better understand the Universe in which we all are situated and thus to learn about ourselves. Teaching science is not about telling students a lot of things about the content. It is about giving them opportunities to chew on things, to dance around a concept, to look at it from different angles, to own it; that is where the learning is taking place.

There are many challenges and obstacles that tribal college students face, both in their educations and in their lives, but challenges are an opportunity for innovation and growth. Innate reservoirs of resourcefulness, creativity, community-mindedness, strength, love, and persistence can turn obstacles into springboards to newer and better approaches to solving problems. The meaning and importance of this research is in encouraging students to claim their power and voice; to hold up a mirror that shows them that when they actively engage and take responsibility for their learning, they can create amazing thoughts and understandings that change the way they see the world. They may also change the way we all see the world.

APPENDIX A: INSTITUTIONAL REVIEW BOARD MATERIALS

A1: UA Human Subjects Approval letter

A2: TOCC Presidential Memo Approval letter

A3: TOCC Research Committee Signatures

A4: Sample Recruitment Script for Students Enrolled in the Course

A5: Sample Recruitment Script for General Collaborators and Student Participants Not Enrolled in the Course

A6: Student Participant Consent Form

A7: Student Participant Assent Form

A8: General Collaborator Consent Form

A1: University of Arizona Human Subjects approval letter

THE UNIVERSITY OF ARIZONA.

Human Subjects Protection Program

1618 E. Helen St.
P.O. Box 245137
Tucson, AZ 85724-5137
Tel: (520) 626-6721
http://irb.arizona.edu

March 18, 2009

Jessie Antonellis, Graduate Student
Advisor: Alberto Arenas, PhD
Teacher & Teacher Education
College of Education
PO Box 210069

CORRECTION: Project number changed (mm 6/18/09)

Project NO. 09-0551-00 Curriculum Development for Cultural Relevance: Investigating the Process of Creating Meaningful Experiences in the Tribal College Science Classroom

Dear Ms. Antonellis:

We received documents concerning your above cited project. Regulations published by the U.S. Department of Health and Human Services [45 CFR Part 46.101(b) (1)] exempt this type of research from review by our Institutional Review Board.

Clearance from official authorities for sites where proposed research is to be conducted must be obtained prior to performance of this study at those sites. Evidence of this must be submitted to the Human Subjects Protection Office.

Exempt status is granted with the understanding that no further changes or additions will be made to the procedures followed (copies of which we have on file) without the review and approval of the Human Subjects Committee and your College or Departmental Review Committee. Any research related physical or psychological harm to any subject must also be reported to each committee.

Thank you for informing us of your work. If you have any questions concerning the above, please contact this office.

Sincerely,

Elizabeth A. Boyd

Elizabeth Boyd, Ph.D.
Assistant Vice-President, Research Compliance & Policy
Office of Responsible Conduct for Research

cc: Departmental/College Review Committee
EB:mm

Arizona's First University – Since 1885

A2: Tohono O’odham Community College Presidential memo approval letter

INTEROFFICE MEMORANDUM

TO: BOARD OF TRUSTEES, TOHONO O’ODHAM COMMUNITY COLLEGE

FROM: **OLIVIA VANEGAS-FUNCHEON, PRESIDENT**

DATE: 9/14/2006

AGENDA ITEM: REARCH PROPOSAL

BACKGROUND:

A research proposal was received from Jessie Antonellis, a doctoral student from the University of Arizona for her doctoral dissertation. This proposal to develop a Physics class for the College would enhance the STEM curriculum and add capacity to the science discipline.

RECOMMENDATION:

The President recommends that the Board of Trustees approve the research proposed by Jessie Antonellis, titled Curriculum Adaptation for Cultural Relevance: A Case Study in the Tribal College Setting; dated September 6, 2006— pending any additional revisions recommended.

A3: Tohono O'odham Community College Research Committee signatures

Tohono O'odham Community College

[illegible]

[illegible]

Institutional Review Board Approval Signature Page

Signature/Date		Signature/Date	
Signature:		Signature:	
Dr. Josel Marlow:		Brenda Eleando-Jones:	
Title: Math Instructor	Date: 5-18-2007	Title: H R Director	Date: 5-18-2007
Signature:		Signature:	
Teresa Newberry:		Orville Aldrich:	
Title: Science Instructor	Date: 5-18-2007	Title: Counselor	Date: 5-18-2007
Signature:		Signature: for ALMA VINCE	
Dr. Douglas St. Clair: 5/18/2007		Alma Vince:	
Title: VP R&D	Date: 5-18-2007	Title: SPO	Date: 5-18-2007

A4: Sample recruitment script for students enrolled in the course

Hello, my name is Jessie Antonellis, and I'm a graduate student at the University of Arizona in the College of Education. My work involves improving science education for Native students in the physical sciences, and I have been approved by the Tohono O'odham Community College President and IRB Committee to conduct a study that looks at the development and teaching of a culturally-relevant introductory physical science course for TOCC students, which is this class. As students in this class, you are invited to participate in the research. This would mean spending some time talking with me outside of class, either one-on-one or with other students who choose to participate in the research. I would be interested to hear your ideas about the class, how including cultural information works and doesn't work, and anything else you can tell me to help me improve the course for the future.

You are in no way obligated to participate in the research, however. You can be a student in this class without being involved in interviews or other outside activities, although I will be making observations that include all of you indirectly. Whether or not you decide to participate in the research, your grade will not be affected one way or the other, and you can still meet with me to talk about your work and your learning any time, regardless of whether or not you're involved with the research. Even if you do decide to participate in the research, you can choose to withdraw at any time.

Thank you very much for letting me tell you about this project. If you would like to be involved in the research, please contact me privately.

A5: Sample recruitment script for general collaborators
and students not enrolled in the course

Hello, my name is Jessie Antonellis, and I'm a graduate student at the University of Arizona in the College of Education. My work involves improving science education for Native students in the physical sciences, and I have been approved by the Tohono O'odham Community College president to conduct a study that examines the creation and implementation of a culturally-relevant introductory physical science course for TOCC students. With the help of people like you, I have been designing this course and am offering it for a second time this semester.

The creation of culturally responsive science curricula is essential for promoting the success of Native students in science; however, there is little to which educators can turn to help them create and implement culturally-relevant curricula. The purpose of this study will be to create such a resource by documenting the process of developing culturally-relevant curriculum for this physical science course.

Developing this curriculum will require collaboration with the college's educators, staff, and students, as well as with educators and scientists from outside the college. If you choose to be involved in this study, you will be allowing your input to be included as part of the documentation of the curriculum development process. What your input will look like is up to you; you may allow me to transcribe a conversation that we have, or to include an email or memo that you write, or to paraphrase advice that you give me about developing the course. Likewise, if you decide to participate in the study, there may be information that you choose *not* to allow me to include.

Thank you very much for giving me your time. If you would like to be involved in this study, please contact me privately.

A6: Student participant consent form

Project Title: *Curriculum Adaptation for Cultural Relevance*

Introduction

You are being invited to take part in a study. The information in this form is provided to help you decide whether or not to take part. I will be available to answer your questions and provide additional information. If you decide to take part in the study, you will be asked to sign this consent form. A copy of this form will be given to you.

What is the purpose of this study?

This project will focus on the process of integrating the curriculum of a tribal college science course into the Tohono O'odham *Himdag*. The purpose of this study will be to create a resource that documents the process of developing a culturally-relevant physical science curriculum. It is hoped that this resource will be a guide for other educators of American Indian students who want to create their own culturally-appropriate science courses.

Why are you being asked to participate?

You are being invited to participate because as a student in this course you have a unique perspective on what this course is like, and your experiences can help inform me about what is good about the course and what could be improved. Your knowledge and input will help me improve this curriculum so that it will be useful to Tohono O'odham Community College and your peers, and will help me create a guide that will be useful for other educators of American Indian students.

How many people will be asked to participate in this study?

All students in the course will be invited to participate; there will be at most 30 participants, though likely fewer.

What will happen during this study?

During Spring 2009, student participants will meet with me, one-on-one or with other participants if you choose, for no more than one hour every week to discuss the your ideas about the class. We will schedule interviews at your convenience at least twice during the semester. If you give your consent, audio-recordings will be made of our meetings. You may also choose to allow me to use your work in this class as data.

☐ I give my permission for my work as data in this study.

☐ I Do Not give my permission for my work as data in this study.

How long will I be in this study?

You can be involved in this study throughout the spring semester of 2009, although you may choose to withdraw prior to the end of the semester.

Are there any risks to me?

The things that you will be doing have very little risk. Although I have tried to avoid risks, you may feel uncomfortable with sharing information with me because I am non-O'odham and I am your instructor.

At any point during an interaction with me, you may choose to deny permission for the information you provide to be included as data. You will also be given the option of reviewing the transcripts of discussions with me. You may deny permission for the use of any information you provided at any time. You may also work with me to "generalize" information that you provide – for instance, you may provide specific details about a topic, but ask that the data only include a very general statement about the topic.

Are there any benefits to me?

There are no direct benefits to you.

This project has the potential to benefit the larger tribal college community as well as other educators of Native students. One of the outcomes of the project will be a model for creating culturally-relevant science curricula for college-level students. Students' experiences with the course will help educators understand how culturally-relevant courses impact students. This may be meaningful for indigenous communities both nationally and internationally; both in the field of science education and potentially in other fields of education.

Will there be any costs to me?

There are no costs for taking part in the study aside from your time. You can potentially meet with me once per week for up to an hour, so you can contribute up to fifteen hours of your time. I would like to conduct at least two half-hour interviews per participant, so you would be asked to contribute at least one hour of your time.

Will I be paid to participate in the study?

You will not be paid to participate.

Will video or audio recordings be made of me during the study?

If you provide your permission for me to do so, I will make an audio recording during our meetings so that we can be certain that your responses are recorded accurately. This will only happen if you check the box below:

☐ I give my permission for audio recordings to be made of me during my participation in this study.

☐ I Do Not give my permission for audio recordings to be made of me during my participation in this study.

Will the information that is obtained from me be kept confidential?

Your records will be confidential. You will not be identified in any reports or publications resulting from the study. It is possible that representatives of the Federal Government or some other group, such as the Human Subjects Protection Program, will want to come to the University of Arizona to review your consent form. If that occurs, a copy of the information may be provided to them but your name will be removed before the information is released.

May I change my mind about participating?

Your participation in this study is voluntary. You may decide to withdraw from the study at any time without fear, harm, duress or penalty. Your participation or non-participation will not affect your status as a student or your grades in this course. Choosing to withdraw from the study will likewise not affect your status as a student.

You may also choose to deny permission for any information you provide to be used as data. You may deny permission at any time.

Whom can I contact for additional information?

You can obtain further information about the study, or voice concerns or complaints about the study, by calling the Principal Investigator, Jessie Antonellis, Ph.D. Candidate, University of Arizona at (520) 305-5710.

If you have questions concerning your rights as a research participant, have general questions, concerns or complaints, or would like to give input about the study and can't reach the project lead, or want to talk to someone other than the project lead, you may call the University of Arizona Human Subjects Protection Program office at (520) 626-6721. (If out of state use the toll-free number 1-866-278-1455.) If you would like to contact the Human Subjects Protection Program electronically, please visit http://www.irb.arizona.edu/suggestions.php.

Your Signature

By signing this form, you affirm that you have read the information contained in the form, that the study has been explained to you, that your questions have been answered and that you agree to take part in this study. You do not give up any of your legal rights by signing this form.

____
Name (Printed)

___________________________________ _______________
Participant's Signature Date signed

Statement by person obtaining consent

I certify that I have explained the research study to the person who has agreed to participate, and that he or she has been informed of the purpose, the procedures, the possible risks and potential benefits associated with participation in this study. Any questions raised have been answered to the participant's satisfaction.

____
Name of study personnel

___________________________________ _______________
Study personnel signature Date signed

A7: Student participant assent form

Project Title: *Curriculum Adaptation for Cultural Relevance*

Introduction

You are being invited to take part in a study. The information in this form is provided to help you decide whether or not to take part. I will be available to answer your questions and provide additional information. If you decide to take part in the study, you and your parent or guardian will be asked to sign this form. A copy of this form will be given to you.

What is the purpose of this study?

This project will focus on the process of integrating the curriculum of a tribal college science course into the Tohono O'odham *Himdag*. The purpose of this study will be to create a resource that documents the process of developing a culturally-relevant physical science curriculum. It is hoped that this resource will be a guide for other educators of American Indian students who want to create their own culturally-appropriate science courses.

Why are you being asked to participate?

You are being invited to participate because as a student in this course you have a unique perspective on what this course is like, and your experiences can help inform me about what is good about the course and what could be improved. Your knowledge and input will help me improve this curriculum so that it will be useful to Tohono O'odham Community College and your peers, and will help me create a guide that will be useful for other educators of American Indian students.

How many people will be asked to participate in this study?

All students in the course will be invited to participate; there will be at most 30 participants, though likely fewer.

What will happen during this study?

During Spring 2009, student participants will meet with me, one-on-one or with other participants if you choose, for no more than one hour every week to discuss the your ideas about the class. We will schedule interviews at your convenience at least twice during the semester. If you give your consent, audio-recordings will be made of our meetings. You may also choose to allow me to use your work in this class as data.

☐ I give my permission for my work as data in this study.

☐ I Do Not give my permission for my work as data in this study.

How long will I be in this study?

You can be involved in this study throughout the spring semester of 2009, although you may choose to withdraw prior to the end of the semester.

Are there any risks to me?

The things that you will be doing have very little risk. Although I have tried to avoid risks, you may feel uncomfortable with sharing information with me because I am non-O'odham and I am your instructor.

At any point during an interaction with me, you may choose to deny permission for the information you provide to be included as data. You will also be given the option of reviewing the transcripts of discussions with me. You may deny permission for the use of any information you provided at any time. You may also work with me to "generalize" information that you provide – for instance, you may provide specific details about a topic, but ask that the data only include a very general statement about the topic.

Are there any benefits to me?

There are no direct benefits to you.

This project has the potential to benefit the larger tribal college community as well as other educators of Native students. One of the outcomes of the project will be a model for creating culturally-relevant science curricula for college-level students. Students' experiences with the course will help educators understand how culturally-relevant courses impact students. This may be meaningful for indigenous communities both nationally and internationally; both in the field of science education and potentially in other fields of education.

Will there be any costs to me?

There are no costs for taking part in the study aside from your time. You can potentially meet with me once per week for up to an hour, so you can contribute up to fifteen hours of your time. I would like to conduct at least two half-hour interviews per participant, so you would be asked to contribute at least one hour of your time.

Will I be paid to participate in the study?

You will not be paid to participate.

Will video or audio recordings be made of me during the study?

If you provide your permission for me to do so, I will make an audio recording during our meetings so that we can be certain that your responses are recorded accurately. This will only happen if you check the box below:

☐ I give my permission for audio recordings to be made of me during my participation in this study.

☐ I Do Not give my permission for audio recordings to be made of me during my participation in this study.

Will the information that is obtained from me be kept confidential?

Your records will be confidential. You will not be identified in any reports or publications resulting from the study. It is possible that representatives of the Federal Government or some other group, such as the Human Subjects Protection Program, will want to come to the University of Arizona to review your consent form. If that occurs, a copy of the information may be provided to them but your name will be removed before the information is released.

May I change my mind about participating?

Your participation in this study is voluntary. You may decide to withdraw from the study at any time without fear, harm, duress or penalty. Your participation or non-participation will not affect your status as a student or your grades in this course. Choosing to withdraw from the study will likewise not affect your status as a student.

You may also choose to deny permission for any information you provide to be used as data. You may deny permission at any time.

Whom can I contact for additional information?

You can obtain further information about the study, or voice concerns or complaints about the study, by calling the Principal Investigator, Jessie Antonellis, Ph.D. Candidate, University of Arizona at (520) 305-5710.

If you have questions concerning your rights as a research participant, have general questions, concerns or complaints, or would like to give input about the study and can't reach the project lead, or want to talk to someone other than the project lead, you may call the University of Arizona Human Subjects Protection Program office at (520) 626-6721. (If out of state use the toll-free number 1-866-278-1455.) If you would like to contact the Human Subjects Protection Program electronically, please visit http://www.irb.arizona.edu/suggestions.php.

Your Signature

By signing this form, you affirm that you have read the information contained in the form, that the study has been explained to you, that your questions have been answered and that you agree to take part in this study. You do not give up any of your legal rights by signing this form.

____
Participants' Name (Printed)

___________________________________ _______________
Participant's Signature Date signed

Parent/Guardian Signature

By signing this form, you affirm that you have read the information contained in the form, that the study has been explained to you, that your questions have been answered and that you give your permission for your child to take part in this study. You do not give up any of your legal rights by signing this form.

____
Parent's/Guardian's Name (Printed)

___________________________________ _______________
Parent's/Guardian's Signature Date signed

Statement by person obtaining consent

I certify that I have explained the research study to the person who has agreed to participate and his or her guardian, and that they have been informed of the purpose, the procedures, the possible risks and potential benefits associated with participation in this study. Any questions raised have been answered to the participant's and his or her guardian's satisfaction.

____
Name of study personnel

___________________________________ _______________
Study personnel signature Date signed

A8: General collaborator consent form

Project Title: ***Curriculum Adaptation for Cultural Relevance***

Introduction

You are being invited to take part in a study. The information in this form is provided to help you decide whether or not to take part. I will be available to answer your questions and provide additional information. If you decide to take part in the study, you will be asked to sign this consent form. A copy of this form will be given to you.

What is the purpose of this study?

This project will focus on the process of integrating the curriculum of a tribal college science course into the Tohono O'odham *Himdag*. The purpose of this study will be to create a resource that documents the process of developing a culturally-relevant physical science curriculum. It is hoped that this resource will be a guide for other educators of American Indian students who want to create their own culturally-appropriate science courses.

Why are you being asked to participate?

You are being invited to participate because you possess expertise that will help inform the creation of this curriculum. Your knowledge and input will help me create a science curriculum that will be useful to Tohono O'odham Community College, and a guide that will be useful for other educators of American Indian students.

How many people will be asked to participate in this study?

It is unknown exactly how many people will participate in this study. No more than 200 individuals total will be invited to participate.

What will happen during this study?

During Spring 2009, I will be continuing work on developing a curriculum for a physical science course that I will also be teaching in Spring 2009. The curriculum development will include focus groups and interviews with collaborators such as yourself. When consent from all participants can be obtained, audio-recordings will be made of these events.

How long will I be in this study?

There is no specific length of time that you may participate in this study. You may choose to provide your input on the course to me at any time, and you may choose to discontinue your participation at any time. The development phase of the project began in August 2007 and will be complete in May 2009, following the completion of the course. You may choose to participate at any time during this period.

Are there any risks to me?

The things that you will be doing have very little risk. Although I have tried to avoid risks, you may feel that some topics we discuss are stressful or upsetting. If this occurs you can stop participating immediately.

At any point during an interaction with me, you may choose to deny permission for the information you provide to be included as data. You will also be given the option of reviewing the transcripts of discussions with me. You may deny permission for the use of any information you provided at any time. You may also work with me to "generalize" information that you provide – for instance, you may provide specific details about a topic, but ask that the data only include a very general statement about the topic.

Are there any benefits to me?

There are no direct benefits to you.

This project has the potential to benefit the larger tribal college community as well as other educators of Native students. One of the outcomes of the project will be a model for creating culturally-relevant science curricula for college-level students. The collaborators' process in creating the curriculum will serve as an example to other educators who are looking to do the same in their own communities. This may be meaningful for indigenous communities both nationally and internationally; both in the field of science education and potentially in other fields of education.

Will there be any costs to me?

There are no costs for taking part in the study aside from your time. In some cases, data collection will take place during regular activities, in which case participation will not require additional time on your part. In other cases, interactions will be in addition to regular activities. In these cases, participation may require up to an hour of your time. Over the course of the Spring 2009 data collection period, it would be possible for you to spend one hour a week with me and thus to contribute up to sixteen hours of your time. The amount of time you spend with me is up to you.

Will I be paid to participate in the study?

You will not be paid for your participation. However, you will receive a certificate indicating your participation in the study.

Will video or audio recordings be made of me during the study?

If you provide your permission for me to do so, I will make audio recordings during our conversations so that we can be certain that your responses are recorded accurately. This will only happen if you check the box below:

☐ I give my permission for audio recordings to be made of me during my participation in this study.

Will the information that is obtained from me be kept confidential?

Your records will be confidential. You will not be identified in any reports or publications resulting from the study, *unless you choose to be*. It is possible that representatives of the Federal Government or some other group, such as the Human Subjects Protection Program, will want to come to the University of Arizona to review your consent form. If that occurs, a copy of the information may be provided to them but your name will be removed before the information is released.

May I change my mind about participating?

Your participation in this study is voluntary. You may decide to withdraw from the study at any time without fear, harm, duress, or penalty. You may also choose to deny permission for any information you provide to be used as data. You may deny permission at any time.

Whom can I contact for additional information?

You can obtain further information about the study, or voice concerns or complaints about the study, by calling the Principal Investigator, Jessie Antonellis, Ph.D. Candidate, University of Arizona at (520) 305-5710.

If you have questions concerning your rights as a research participant, have general questions, concerns or complaints, or would like to give input about the study and can't reach the project lead, or want to talk to someone other than the project lead, you may call the University of Arizona Human Subjects Protection Program office at (520) 626-6721. (If out of state use the toll-free number 1-866-278-1455.) If you would like to contact the Human Subjects Protection Program electronically, please visit http://www.irb.arizona.edu/suggestions.php.

Your Signature

By signing this form, you affirm that you have read the information contained in the form, that the study has been explained to you, that your questions have been answered and that you agree to take part in this study. You do not give up any of your legal rights by signing this form.

____

Name (Printed)

___________________________________ _______________
Participant's Signature Date signed

Statement by person obtaining consent

I certify that I have explained the research study to the person who has agreed to participate, and that he or she has been informed of the purpose, the procedures, the possible risks and potential benefits associated with participation in this study. Any questions raised have been answered to the participant's satisfaction.

____
Name of study personnel

___________________________________ _______________
Study personnel signature Date signed

APPENDIX B: COURSE MATERIALS

B1: PHY 121 Syllabus
B2: PHY 121 Midterm Exam
B3: PHY 121 Final Exam

B1: PHY 121 syllabus

PHYS 121—Introductory Physics I

Spring 2008

Class Times: Fridays, 9-12 and 12:30-2:30
Field trips TBA

Instructor: Jessie Antonellis
jcantone@email.arizona.edu
(508) 776-4162 – cell

Office Hours: Fridays, 3:00-4:00 or by appt.

Text: *College Physics*, Young & Geller, 8^{th} Edition, Pearson, 2007

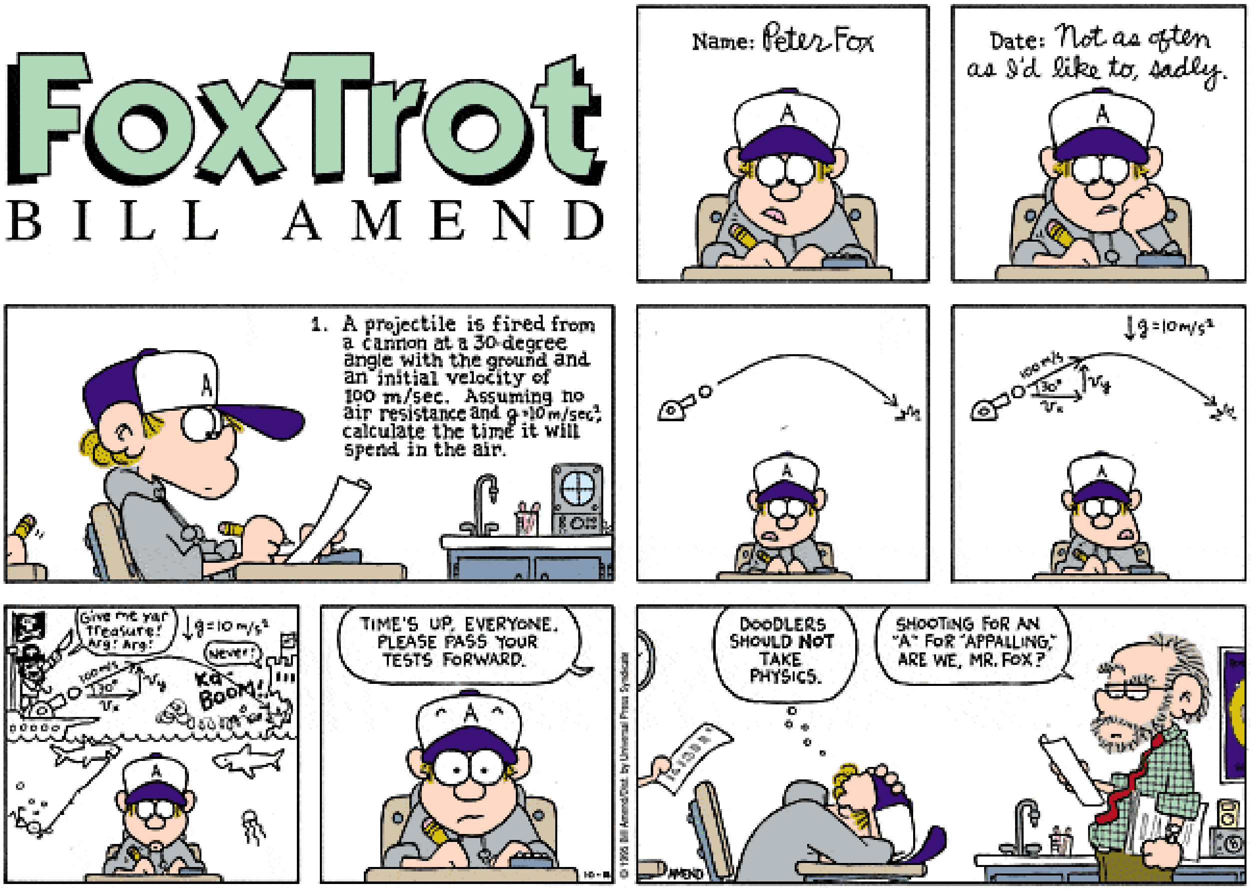
Course Description
Introduction to general physics. Includes mechanics (motion), heat, energy, and gravity. Discusses the systems that organize the universe and the ways in which all things in the universe are connected. Useful for programs requiring a one-year, non-calculus based physics course.

Course Goals
This course will provide a culturally-relevant experience with introductory physics, which will help you develop a meaningful connection with the field of science and aid you in your future studies. The course will also emphasize the development of essential skills, such as critical thinking, math, communication and the use of technology.

By the end of the semester students will be able to:
- discuss the nature of science.
- identify the O'odham perspective(s) of science and compare and contrast different cultures' perspectives on and uses of science.
- use critical thinking and an understanding of physical concepts to solve problems.
- pose questions about the physical world and devise experiments to investigate them.
- explain and write about physical concepts covered in the course.
- utilize technology(ies) to enhance and communicate their learning.
- gain a better understanding of the world.
- use science-related skills independently.

Tentative Grading Scheme

Homework	5-10%
Class Participation	50%
Activity Reports	15%
Exams	15%
TBA	10%


FoxTrot
BILL AMEND
Name: Peter Fox
Date: Not as often as I'd like to, sadly.
1. A projectile is fired from a cannon at a 30-degree angle with the ground and an initial velocity of 100 m/sec. Assuming no air resistance and g=10 m/sec², calculate the time it will spend in the air.
g=10 m/s²
100 m/s
30°
Give me yar Treasure! Arg! Arg!
Never!
Ka-Boom!
TIME'S UP, EVERYONE. PLEASE PASS YOUR TESTS FORWARD.
DOODLERS SHOULD NOT TAKE PHYSICS.
SHOOTING FOR AN "A" FOR "APPALLING," ARE WE, MR. FOX?
AMEND

B2: PHY 121 midterm exam

Physics 121 – Spring 2008
Midterm

Due March 21st, 2008

Name: ____

This is a three-part midterm. The first two parts are a take-home exam that you will return on March 21st. The second part will be a project that takes place in class.

The two parts of the take-home exam are: Part I – a problem set with conceptual questions, and Part II – an essay about culture and science. I expect you to show all your work and write complete, thoughtful answers with full sentences. You may use your book, and you may work with your classmates, but you must prepare your own solution and write in your own words. To perform well on this exam, you should review the concepts we have covered in class, refer to your book for explanations, and contact me by email or by phone (508-776-4162) if you have any questions.

The in-class project will be to design, build and test a vehicle that can perform well on designated tasks. You do not need to prepare anything for the in-class project now, but you will be expected to answer questions about physical concepts that affect your vehicle's performance.

Complete this midterm and submit it NO LATER THAN our next class. You can submit the exam early by emailing it to jcantone@email.arizona.edu, so being absent from class on the 21st is no excuse for turning it in late. Late exams will not be accepted.

Part I

Directions:

Below you will find a description of a scenario. You are to apply everything you have learned about physics to explain what is happening in this scenario. There are a series of questions to guide your thinking.

<u>Scenario</u>:

Two rockets start at rest. Both rockets have a mass of 0.5 kg. Both rockets are powered by air pressure. Rocket A is 12 feet off the ground and takes off at a zero-degree angle (parallel with the ground) facing due east. Rocket B takes off from the ground at a 90 degree angle (straight up). Rocket B stays in the air for 9 seconds.

1. Draw the path of each rocket.

2. What forces act on the rockets?

3. When are the rockets accelerating? (Hint: There are 2 accelerations for each rocket.)

4. What does Newton's 1st law have to do with the rockets' motion?

5. What does Newton's 2nd law have to do with the rockets' motion?

6. What does Newton's 3rd law have to do with the rockets' motion?

7. How long does Rocket A stay in the air?

8. In which direction (e.g. the up-down direction, the left-right direction) do the rockets have a constant velocity?

9. If Rocket A traveled 0.15 miles east, what was its initial velocity in feet per second?

10. How far did Rocket B travel east? (Assume it is a windless day.)

11. What was Rocket B's initial velocity in feet per second?

12. How high did Rocket B go?

13. Which rocket had a greater kinetic energy at the time it hit the ground?

14. Which rocket had a greater potential energy at the time it first took off?

15. Which rocket had a greater potential energy at the highest point of its path?

16. If it took Rocket B 0.2 seconds to detach from its launcher, which has 10 cm long casing, how much work did the air in the launcher do on the rocket? What was the power of the air in the launcher? (Hint: You will need these equations: F=ma and W=FxD, P=W/t

Part II

Essay:

Imagine that you are having a discussion with a college classmate about how science is different in different cultures. Your classmate argues that science is objective and is the same for everyone. In your own words, explain how science is influenced by culture. Include at least one example of how your community does science or uses scientific knowledge. Make your argument clearly so your classmate will be able to understand your point.

Write at least two good paragraphs but no more than one page.

Part III

In Class Project: Newton-Powered Vehicles

Directions:

Using your knowledge of Newton's laws of motion, you will design and construct a vehicle that is powered by Newton's 3rd law. You may use any materials available to you in our classroom (i.e. anything that doesn't belong to other classes). Your vehicle must be able to travel a 3-meter distance on a path 1 meter wide. It can only be powered by materials "on board"; that is, you can't push it or drop it to make it go.

The supplies you will have access to are listed below. You can also bring in supplies from home if there's something you have in mind.

Supplies:

Balloons
Toy cars
Film canisters
Baking soda
Vinegar
String
Paper clips
Glue sticks
Scissors
Knife
Straws
Pencils
Bobs
Rulers
Tape

AT HOME:

Think about what materials you might use in your design.

Design a vehicle that is powered by Newton's 3rd law.

Sketch your design and prepare some directions on how you'll construct it.

Prepare brief answers to the following questions:

- How did you make your decision(s) about your design?
- What powers your vehicle?
- How do Newton's laws of motion affect your vehicle?
- What forces are acting on your vehicle, and how do you use or minimize them?

IN CLASS:

Construct your vehicle.

Test your vehicle.

Prepare a brief presentation (5-10 min.) on your vehicle, which includes the answers to the questions above, as well as the questions below:

- What did you change as you were building and testing your design?
- How did your vehicle perform in testing?
- What else can you tell us about your vehicle? (e.g. its velocity, its mass, its acceleration, etc.)

B3: PHY 121 final exam

Physics 121 – Final Exam

Name: ________________________

Date: _________________________

Parts:

1. Lab experience: Marbles on a ramp **25 points**
    a. Set up an experiment that investigates the relationship between the height of the ramp and the displacement of a cup at the bottom of the ramp.
    b. When you change the height at which you drop the marble, what about the marble changes?
    c. What does work on the marble?
    d. What does work on the cup?
    e. How is energy conserved in this scenario? How is it *transformed*? How is it *transferred*?
    f. What kind of collision is demonstrated in this scenario, elastic or inelastic? How can you tell?
    g. How is momentum conserved in this scenario?
    h. How does Newton's 1st law come into play?
    i. How does Newton's 2nd law come into play?
    j. Where in this scenario do you see acceleration?
    k. Create a data table. What goes in each column?
    l. How much data is enough to demonstrate the relationship between the two variables?
    m. What does the relationship look like?
    n. Describe a real-life scenario that is similar to what is happening in this experiment.

2. Using your understanding of momentum and impulse, design a product that will protect a ball of clay that is dropped from a height of 7 feet. Be able to describe your design process (how you started, what decisions you made, what you tried, what you changed, what you ended up with). Be able to explain how your product protects the clay, using the concepts of momentum and impulse. **20 points**

3. What does culture have to do with science? What does science have to do with culture? **20 points**

4. What is science? What is physics? Provide responses in your own words. **20 points**

5. How would you explain what a field is? How does it relate to gravity? **5 points**

6. How does a vacuum “suck” things into it? In terms of fluid mechanics, what is really happening? What exerts the force? **5 points**

7. Choose one law of thermodynamics and describe it in your own words. Give an example to support your description. **5 points**

REFERENCES

Abdal-Haqq, I. (1994). *Culturally responsive curriculum. ERIC Digest.* ED370936.

Agbo, S. (2001). Enhancing success in American Indian students: Participatory research at Akwesasne as part of the development of a culturally relevant curriculum. *Journal of American Indian Education, 40*(1), 31-56.

Agrawal, A. (1995). Dismantling the divide between indigenous and scientific knowledge. *Developing and Change, 26*(3), 413-439.

Aguiar, O. G., Mortimer, E. F., & Scott, P. (2010). Learning from and responding to students' questions: The authoritative and dialogic tension. *Journal of Research in Science Teaching*, *47*(2), 174-193.

Aikenhead, G. S. (1996). Science education: Border crossing in the subculture of science. *Studies in Science Education*, *27,* 1-52.

Aikenhead, G., & Jegede, O. J. (1999). Cross-cultural science education: A cognitive explanation of a cultural phenomenon. *Journal of Research in Science Teaching*, *36*(3), 269-287.

Allen, N., Resta, P., & Christal, M. (2002). Technology and tradition: The role of technology in Native American schools. *TechTrends*, *46*(2), 50-55.

Aluli-Meyer, M. (2008). Indigenous and authentic: Hawaiian epistemology and the Triangulation of Meaning. In N. K. Denzin, Y. S. Lincoln, & L. T. Smith (Eds.), *Handbook of critical and indigenous methodologies* (pp. 217-232). Thousand Oaks, CA: Sage.

Antonellis, A. (2011). *Impulse 101*. (Master's thesis, Bauhaus-Universität Weimar, 2006). Retrieved from http://www.anthonyantonellis.com/media/k2/attachments/Impulse101_version_2.0.pdf).

Apthorp, H., D'Amato, E., & Richardson, A. (2002). Effective standards-based practices for Native American students: A review of research literature. Aurora, Colorado: Mid-Continent Research for Education and Learning.

Aragon, S. R. (2002). An investigation of factors influencing classroom motivation for postsecondary American Indian/Alaska Native students. *Journal of American Indian Education, 41*(1), 1-18.

Aschbacher, P. R., Li, E., & Roth, E. J. (2010). Is science me? High school students' identities, participation and aspirations in science, engineering, and medicine. *Journal of Research in Science Teaching*, *47*(5), 564-582.

Assembly of First Nations. (2012). Cultural competency report. Final report.

Atkinson, J. (2001). Privileging Indigenous research methodologies. Presentation at the Indigenous Voices Conference, Rainforest CRC: Cairns, Queensland.

Au, K., & Jordan, C. (1981). Teaching reading to Hawaiian children: Finding a culturally appropriate solution. In H. Trueba, G. Guthrie, and K. Au (Eds.), *Culture and the bilingual classroom: Studies in classroom ethnography* (pp. 139-152). Rowley, Massachusetts: Newbury.

Babco, E. (2005). The status of Native Americans in science and engineering. Commission on Professionals in Science and Technology. Prepared for the National Academy of Engineering Workshop on Engineering Studies at the Tribal Colleges, March 15, 2005.

Bajracharya, H., & Brouwer, W. (1997). A narrative approach to science teaching in Nepal. *International Journal of Science Education*, *19*(4), 429-446.

Baker, D. (1996). Does 'indigenous science' really exist? *Australian Science Teachers Journal*, *42*(1), 18-20.

Bakhtin, M. M. (1934). Discourse in the novel. In M. Holquist (Ed.) and C. Emerson & M. Holquist (trans.), *The Dialogic Imagination*. Austin: University of Texas Press (1981).

Balgopal, M., Wallace, A. M., & Dahlberg, S. (2012). Writing to learn ecology: A study of three populations of college students. *Environmental Education Research*, *18*(1), 67-90.

Ballenger, C. (1997). Social identities, moral narratives, scientific argumentation: Science talk in a bilingual classroom. *Language and Education*, *11*, 1-14.

Banks, J. A. (1994). *Multicultural education* (3rd ed.). Boston: Allyn & Bacon.

Barca, D., & Arenas, A. (2010). Words of caution on indigenous knowledge and education. *Educational Practice & Theory*, *32*(1), 5-28.

Barnhardt, C. (1994). *Life on the other side: Alaska Native teacher education students and the University of Fairbanks*. Ph.D. dissertation, University of British Columbia.

Barnhardt, R. (2000). Teaching/learning across cultures: strategies for success. In R. Neil (Ed.), *Voice of the Drum* (pp. 167-176). Brandon, Manitoba: Kingfisher Publications.

Bartolomé, L. I. (1994). Beyond the methods fetish: Toward a humanizing pedagogy. *Harvard Educational Review*, *64*(2), 173-194.

Basu, S. J. (2006). How urban youth express critical agency in a 9th grade conceptual physics classroom. Ph.D. dissertation, Columbia University, United States -- New York. Retrieved June 29, 2010, from Dissertations & Theses: Full Text. (Publication No. AAT 3213478).

Battiste, M. (2008a). Animating Indigenous Knowledge in education: From resilience to renaissance. Keynote. World Indigenous People's Conference in Education (Wipce).

December 11, 2008, Melbourne, Australia. Accessed 26 February, 2011 from http://www.usask.ca/education/people/battistem/WIPCE-2008-Keynote.pdf

Battiste, M. (2008b). Research ethics for protecting indigenous knowledge and heritage: Institutional and researcher responsibilities. In N. K. Denzin, Y. S. Lincoln, & L. T. Smith (Eds.), *Handbook of critical and indigenous methodologies* (pp. 497-509). Thousand Oaks, CA: Sage.

Belgarde, M. J. (1992). *The performance and persistence of American Indian undergraduate students at Stanford University*. Unpublished dissertation, Stanford University.

Belgarde, M. J., & LoRé, R. K. (2003-2004). The retention/intervention study of Native American undergraduates at the University of New Mexico. *Journal of College Student Retention, 5*(2), 175-203Belgarde, M., Mitchell, R., & Arquero, A. (2002). What do we have to do to create culturally responsive programs? The challenge of transforming American Indian teacher education. *Action in Teacher Education, 24*(2), 42-54.

Belgarde, M. J., Mitchell, R. D., & Arquero, A. (2002). What do we have to do to create culturally responsive programs? The challenge of transforming American Indian teacher education. *Action in Teacher Education*, *24*(2), 42-54.

Benjamin, D., Chambers, S. L., & Reiterman, G. (1993). A focus on Native American college persistence. *Journal of Native American Education*, *32*(2), 24-40.

Bessarab, D. (2008). Yarning about different types of yarning in the doing of Indigenous research. *Fourth International Congress of Qualitative Inquiry*, Illinois, May 14-17.

Bhabha, H. K. (1994). *The location of culture*. New York: Routledge.

Bishop, R. (1999). Collaborative storytelling: Meeting Indigenous people's desires for self-determination. Paper presented at the *World Indigenous People's conference*, Albuquerque, New Mexico, June 15-22.

Bishop, R. (2008). Kotahitanga: Kaupapa Māori in mainstream classrooms. In N. K. Denzin, Y. S. Lincoln, & L. T. Smith (Eds.), *Handbook of critical and indigenous methodologies* (pp. 439-458). Thousand Oaks, CA: Sage.

Bishop, R., & Glynn, T. (1992). He kanohi kitea: Conducting and evaluating educational research. *New Zealand Journal of Educational Studies*, *27*(2), 125-135

Boyer, P. (1997). *Native American colleges: Progress and prospects*. San Francisco, CA: Jossey-Bass Inc., Publishers.

Brandt, C. B. (2008a). Discursive geographies in science: Space, identity, and scientific discourse among Indigenous women in higher education. *Cultural Studies of Science Education*, *3*(3), 703-730.

Brandt, C. B. (2008b). Scientific discourse in the academy: A case study of an American Indian undergraduate. *Science Education*, *92*(5), 825-847.

Brayboy, B.M. (2008, February). *Jenny and the beanstalk: Indigenous knowledges and teacher education*. Keynote address at the University of Arizona 21st annual LRC Graduate Student Colloquy, Tucson, Arizona.

Brayboy, B. M., & Deyhle, D. (2000). Insider-outsider: Researchers in American Indian communities. *Theory into Practice*, *39*(3), 163-169.

Brickhouse, N. W., Lowery, P., & Schultz, K. (2000). What kind of girl does science? The construction of school science identities. *Journal of Research in Science Teaching*, *37*(5), 441-458.

Brown, B. A. (2006). “It isn’t no slang that can be said about this stuff”: Language, identify, and appropriating science discourse. *Journal of Research in Science Teaching*, *43*(1), 96-126.

Brown, L. L., & Robinson Kurpius, S. E. (1997). Psychosocial factors influencing academic persistence of American Indian college students. *Journal of College Student Development*, *38*(1), 3-12.

Bruner, J. (1996). *The culture of education.* Cambridge, Massachusetts & London, England: Harvard University Press.

Burhansstipanov, L., Christopher, S., & Schumacher, A. (2005). Lessons learned from community-based participatory research in Indian country. *Cancer Control*, *25*, Cancer, Culture and Literacy Supplement, 70-76.

Cajete, G. (1988). Motivating American Indian students in science and math. ERIC Digest. ED296812.

Cajete, G. (1999a). *Igniting the sparkle: An Indigenous science education model.* Skyland, North Carolina: Kivaki Press.

Cajete, G. (1999b). The Native American learner and bicultural science education. In K. G. Swisher & J. W. Tippeconnic III (Eds.), *Next steps: Research and practice to advance Indian education*, (pp. 135-160). Charleston, West Virginia: ERIC Clearinghouse on Rural Education and Small Schools.

Cajete, G. (2000). *Native science: Natural laws of interdependence*. Santa Fe: Clear Light Publishers.

Cajete, G. (2008). Seven orientations for the development of Indigenous science education. In N. K. Denzin, Y. S. Lincoln, & L. T. Smith (Eds.), *Handbook of critical and indigenous methodologies* (pp. 487-496). Thousand Oaks, CA: Sage.

Cajete, G. (2010). Re-building sustainable indigenous communities: Applying Native science. Opening plenary for the College Board's Native American Student Advocacy Institute, 19 April 2010.

Calabrese Barton, A., Tan, E., & Rivet, A. (2008). Creating hybrid spaces for engaging school science among urban middle school girls. *American Educational Research Journal*, *45*(1), 68-103.

Campbell, A. (1991). Are traditional and modern education incompatible? *Winds of Change, 6*(4), 100-105, 108-109.

Cazden, C., & Leggett, E. (1981). Culturally responsive education: Recommendations for achieving Lau remedies II. In H. Trueba, G. Guthrie, & K. Au (Eds.), *Cultural and the bilingual classroom: Studies in classroom ethnography* (pp. 69-86). Rowley, Massachusetts: Newbury.

Chang, P. J., & Rosiek, J. (2003). Antic-colonialist antinomies in a biology lesson: A sonata-form case study of cultural conflict in a science classroom. *Curriculum Inquiry*, *33*(3), 251-290.

Chisholm, I. M. (1994). Preparing teachers for multicultural classrooms. *Journal of Educational Issues of Language Minority Students*, *14,* 43-67.

Chrisjohn, R. D., & Peters, M. (1986). The right-brained Indian: Fact or fiction? *Journal of American Indian Education*, *25*(2), 1-7.

Cleary, L. M., & Peacock, T. D. (1998). *Collected wisdom: American Indian education*. Boston: Allyn & Bacon.

Cobern, W. (1991). *World view theory and science education research*. NARST Monograph No. 3. Cincinnati, OH: National Association for Research in Science Teaching.

Cole, J. S., & Denzine, G.M. (2002). Comparing the academic engagement of American Indian and white college students. *Journal of American Indian Education*, *41*(1), 19-34.

Cook-Sather, A. (2002). Authorizing students' perspectives: towards trust, dialogue, and change in education. *Education Researcher*, *31*(4), 3-14.

Curran, D. (1995). No matter what others think, you can reach the stars. *Mercury*, *24*(3), 17-19.

Curtis, A.C. (1998). Creating culturally responsive curriculum: Making race matter. *The Clearing House*, *71*(3), 135-139.

Darby, J. T. (2000). Teaching the Native American [Review]. *American Indian Culture and Research Journal*, *24*(2), 199-200.

Deloria, V. Jr., & Wildcat, D. R. (2001). *Power and place: Indian education in America*. Golden, Colorado: American Indian Graduate Center & Fulcrum Resources.

Demmert, W. G. & Towner, J. C. (2003). A review of the research literature on the influences of culturally based education on the academic performance of Native American students. Portland, Oregon: Northwest Regional Educational Laboratory.

Denzin, N. K., & Lincoln, Y. S. (Eds.). (2005a). *Handbook of qualitative research*. Thousand Oaks, CA: Sage.

Denzin, N. K., & Lincoln, Y. S. (2005b). Introduction: The discipline and practice of qualitative research. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 1-32). Thousand Oaks, CA: Sage.

Denzin, N. K., & Lincoln, Y. S. (2008). Introduction: Critical methodologies and indigenous inquiry. In N. K. Denzin, Y. S. Lincoln, & L. T. Smith (Eds.), *Handbook of critical and indigenous methodologies* (pp. 1-20). Thousand Oaks, CA: Sage.

Dodd, J. M., Garcia, F. M., Meccage, C., & Nelson, J. R. (1995). American Indian student retention. *NASPA Journal*, *33*(1), 72-78.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher*, *23*(7), 5-12.

Dukepoo, F. (2001). The Native American Honor Society: Challenging Indian students to achieve. In K. James (Ed.), *Science and Native American communities: Legacies of pain, visions of promise*, (pp. 36-42). Lincoln & London: University of Nebraska Press.

Dunbar, C. Jr. (2008). Critical race theory and Indigenous methodologies. In N. K. Denzin, Y. S. Lincoln, & L. T. Smith (Eds.), *Handbook of critical and indigenous methodologies* (pp. 85-99). Thousand Oaks, CA: Sage.

Duran, B. J., Dugan, T., & Weffer, R. (1998). Language minority students in high school: The role of language in learning biology concepts. *Science Education*, *82*, 311-341.

Dyck, L. (2001). A personal journey into science, feminist science, and Aboriginal science. In K. James (Ed.), *Science and Native American communities: Legacies of pain, visions of promise*, (pp. 22-28). Lincoln & London: University of Nebraska Press.

Engle, R. A., & Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and Instruction*, *20*, 399-484.

Erickson, W. (1994). *Sharing the desert: The Tohono O'odham in history*. Tucson: University of Arizona Press.

Erickson, F., & Mohatt, G. (1982). Cultural organization and participation structures in two classrooms of Indian students. In G. Spindler, (Ed.), *Doing the ethnography of schooling*, (pp. 131-174). New York: Holt, Rinehart & Winston.

Evans, M., Hole, R., Berg, L. D., Hutchinson, P., & Sookraj, D. (2009). Common insights, differing methodologies: toward a fusion of indigenous methodologies, participatory action research, and White studies in an Urbana aboriginal research agenda. *Qualitative Inquiry*, *15*(5), 893-910

Fang, Z. (2005). Scientific literacy: A systemic functional linguistics perspective. *Science Education*, *89*(2), 335-347.

Fenelon, J. V. & LeBeau, D. (2006). Four directions for Indian education: Curriculum models for Lakota and Dakota teaching and learning. In Abu-Saad, I. & Champagne, D. (Eds.), *Indigenous education and empowerment: International perspectives*. Lanham: Altamira Press.

Fisher, P. A., & Ball, T. J. (2003). Tribal participatory research: Mechanisms of a collaborative model. *American Journal of Community Psychology*, *32*(3-4), 207-216.

Fradd, S. H., Lee, O., Sutman, F.X., & Saxton, M. K. (2002). Materials development promoting science inquiry with English language learners: A case study. *Bilingual Research Journal*, *25*(4), 479-501.

Fusco, C. (1995). *English is broken year: Notes on cultural fusion in the Americas*. New York: New Press.

Fucso, D. (2001). Creating relevant science through urban planning and gardening. *Journal of Research in Science Teaching*, *38*(8), 860-877.

Gallagher, B. (2000). Teaching (Native) America. *The Nation*, *270*(22), 36-38.

Gates, M. (2006). Native Americans find their niche in technology. *Diversity/careers in engineering & information technology*, Summer/Fall 2006. Retrieved October 19, 2008 from http://www.diversitycareers.com.

Gay, G. (2000). *Culturally responsive teaching: Theory, research and practice*. New York: Teachers College Press.

Gee, J. P. (1996). *Social linguistics and literacies: Ideology in discourses (2nd ed.)*. London: Falmer.

Gilliland, H. (1999). *Teaching the Native American*. Dubuque, Iowa: Kendall/Hunt Publishing Company.

Giroux, H. (1985). Introduction. In P. Freire, *The politics of education: Culture, power and liberation* (pp. xi-xxv). South Hadley, MA: Bergin & Garvey.

Giroux, H. (1992). *Border crossings: Cultural workers and the politics of education*. New York: Routledge.

Gonzalez-Espada, W. J., & Oliver, J. S. (2002). Making Puerto Rican high school physics contextual and culturally relevant: A statistical analysis of influencing factors. In Proceedings of the Annual International Conference of the Association for the Education of Teachers in Science, Charlotte, NC, January 10-13, 2002.

Grande, S. (2008). Red pedagogy: The un-methodology. In N. K. Denzin, Y. S. Lincoln, & L. T. Smith (Eds.), *Handbook of critical and indigenous methodologies* (pp. 233-254). Thousand Oaks, CA: Sage.

Grant, A. & Gillespie, L. (1993). Joining the Circle: A Practitioner's Guide to Responsive Education for Native Students. Charleston, West Virginia: ERIC Clearinghouse on Rural Education and Small Schools.

Grater, S., & Antonellis, J. (In press). Tribal college faculty motivations for integrating science & culture. *Mellon Tribal College Research Journal*.

Guba, E. G., & Lincoln, Y. S. (2005). Paradigmatic controversies, contradictions, and emerging confluences. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 191-215). Thousand Oaks, CA: Sage.

Gutiérrez, K. D., Baquedano-López, P., Alvarez, H., & Chiu, M. M. (1999). Building a culture of collaboration through hybrid language practices. *Theory into Practice, 38*, p. 87–93.

Gutiérrez, K. D., Baquedano-López, P., & Tejada, C. (1999a). Rethinking diversity: Hybridity and hybrid language practices in the third space. *Mind, culture, and activity*, *6*(4), 286-303.

Gutiérrez, K., Rymes, B., & Larson, J. (1995). Script, counterscript and underlife in the classroom: James Brown versus *Brown v. Board of Education*. *Harvard Educational Review*, *65*(3), 445-471.

Hammersley, M., & Atkinson, P. (1996). *Ethnography: Principles in practice*. New York: Tavistock.

Hankes, J. E. (1996). *Investigating the correspondence between Native American pedagogy and constructivist based instruction.* Paper presented at the Annual Convention of the American Educational Research Association, New York, New York.

Hardesty, D. L. (1977). *Ecological anthropology*. New York: Wiley.

Hayward, J. W. (1984). *Perceiving ordinary magic: Science and intuitive wisdom*. Boulder, CO: Shambala Publishing Company.

HeavyRunner, I., & DeCelles, R. (2002). Family education model: Meeting the student retention challenge. *Journal of American Indian Education*, *41*(2), 29-37.

Hermes, M. (2000). The scientific method, Nintendo, and Eagle feathers: Rethinking the meaning of “culture-based” curriculum at an Ojibwe tribal school. *International Journal of Qualitative Studies in Education*, *13*(4), 387-4000.

Hobson, B. T. (1994). *Cultural values and persistence among Comanche college students*. Ph.D. dissertation, University of Oklahoma.

Huang, H. J. (2006). Listening to the language of constructing science knowledge. *International Journal of Science Education*, *4*(3), 391-415.

Huffman, T. E. (2001). Resistance theory and the transculturation hypothesis as explanations of college attrition and persistence among culturally traditional American Indian students. *Journal of American Indian Education*, *40*(3), 1-23.

Huffman, T. E., Sill, M. L., & Brokenleg, M. (1986). College achievement among Sioux and White South Dakota students. *Journal of American Indian Education*, *25*(1), 32-38.

Irvine, J. (1990). *Black students and school failure*. Westport, CT: Greenwood.

Israel, B., Schulz, A. J., Parker, E. A., & Becker, A. B. (1998). Review of community-based research: Assessing partnership approaches to improve public health. *Annual Review of Public Health*, *19*(1), 173-202.

James, J. A. (1981). Higher educational needs of Indian students. *Integrateducation*, *19*(8), 7-12.

James, K., (ed.). (2001). *Science and Native American communities: Legacies of pain, visions of promise*. Lincoln & London: University of Nebraska Press.

James, K. (2001a). Culture: The spirit beneath the surface. In K. James (Ed.), *Science and Native American communities: Legacies of pain, visions of promise*, (pp. 45-49). Lincoln & London: University of Nebraska Press.

James, K. (2001b). Fires need fuel: Merging science education with American Indian community needs. In K. James (Ed.), *Science and Native American communities: Legacies of pain, visions of promise,* (pp. 1-8). Lincoln & London: University of Nebraska Press.

Jegede, O. J. (1995). Collateral learning and the eco-cultural paradigm in science and mathematics education in Africa. *Studies in Science Education*, *25*, 97-137.

Jegede, O. J. (1997). School science and the development of scientific culture: A review of contemporary science education in Africa. *International Journal of Science Education*, *19*, 1-20.

Jegede, O. J., & Aikenhead, G. S. (1999). Transcending cultural borders: Implications for science teaching. *Research in Science & Technological Education*, *17*(1), 45-66.

John, G. (2001). Trodding the circle from Indian community to university research and back. In K. James (Ed.), *Science and Native American communities: Legacies of pain, visions of promise*, (pp. 63-68). Lincoln & London: University of Nebraska Press.

Johnson, G. (2003). Resilience, a story: A postcolonial position from which to [re]view Indian education framed in "at-risk" ideology. *Educational Studies, 34*(2), 182-197.

Johnson, V., Benham, M., & VanAlstine, M. (2002). Native leadership: Advocacy for transformation, culture, community and sovereignty. In M. Benham and W. Stein (Eds.), *The Renaissance of American Indian Higher Education: Capturing the Dream* (pp. 149-165). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Jones, A. & Jenkins, K. (2008). Rethinking collaboration: Working the indigene-colonizer hyphen. In N. K. Denzin, Y. S. Lincoln, & L. T. Smith (Eds.), *Handbook of critical and indigenous methodologies* (pp. 471-486). Thousand Oaks, CA: Sage.

Jordan, C. (1985). Translating culture: From ethnographic information to educational program. *Anthropology and Education Quarterly*, *16*, 105-123.

Kahakalau, K. (2004). Indigenous heuristic action research: Bridging western and Indigenous research methodologies. *Hulili: Multidisciplinary research on Hawaiian well-being*, *1*(1), 19-33.

Kanu, Y. (2006). Getting them through the college pipeline: Critical elements of instruction influencing school success among Native Canadian high school students. *Journal of Advanced Academics*, *18*(1), 116-145.

Kaulback, B. (1997). Styles of learning among Native children: A review of the research. In B. Robinson Shade (Ed.), *Culture, style and the educative process: Making schools work for racially diverse students* (pp. 92-104). Springfield, Illinois: Charles C. Thomas, Publisher, Ltd.

Kawageley, O. (2001). Tradition and education: The world made seamless again. In K. James (Ed.), *Science and Native American communities: Legacies of pain, visions of promise*, (pp. 51-56). Lincoln & London: University of Nebraska Press.

Kawagley, A. O., & Barnhardt, R. (1998). Education indigenous to place: Western science meets Native reality. Alaska Native Knowledge Network.

Kawagley, A. O., Norris-Tull, D., & Norris-Tull, R. (1995). Incorporation of the worldviews of Indigenous cultures: A dilemma in the practice and teaching of Western science. Paper presented at the Third International History, Philosophy and Science Teaching Conference, Minneapolis, MN, October 29 – November 2, 1995.

Kenny, C. (2000). A sense of place: Aboriginal research as ritual practice. In Neil, R. (ed.), *Voice of the drum: Indigenous education and culture*, Brandon, Man.: Kingfisher, p. 139-150.

Kerbo, H. R. (1981). College achievement among Native Americans: A research note. *Social Forces*, *59*(4), 1275-1280.

Kieren, T. (1992). Rational and fractional numbers as mathematical and personal knowledge: Implications for curriculum and instruction. In G. Leinhardt, R. Putnam, & R. Hattrup (Eds.), *Analysis of arithmetic for mathematics teaching*, (pp. 323-271). Hillsdale, New Jersey: Erlbaum.

Kirkness, V. J., & Barnhardt, R. J. (1991). First Nations and higher education: The four r's – Respect, relevance, reciprocity, responsibility. *Journal of American Indian Education*, *30*(3), 1-15.

Knowles, M. (1973). *The adult learner: A neglected species.* Madison, Wisconsin: American Society for Training and Development.

Kovach, M. (2009). *Indigenous methodologies: Characteristics, conversations, and contexts*. Toronto: University of Toronto Press.

Kratochwill, T. R., McDonald, L., Young Bear-Tibbitts, H., & Levin, J. R. (2001). *Families and schools together: An experimental analysis of a parent-mediated early intervention program for at-risk American Indian children*. Final Report, OERI. Madison, WI: Wisconsin Center for Education Research.

Krugly-Smolska, E. (1994). An examination of some difficulties in integrating Western science into societies with an Indigenous scientific tradition. *Interchange*, *25*(4), 325-334.

Ladson-Billings, G. (1990). Like lightning in a bottle: Attempting to capture the pedagogical excellence of successful teachers of Black students. *International Journal of Qualitative Studies in Education*, *3*, 335-344.

Ladson-Billings, G. (1992a). Liberatory consequences of literacy: A case of culturally relevant instruction for African American students. *The Journal of Negro Education*, *61*, 378-391.

Ladson-Billings, G. (1992b). Reading between the lines and beyond the pages: A culturally relevant approach to literacy teaching. *Theory into Practice, 31*, 312-320.

Ladson-Billings, G. (1994). *The dreamkeepers: Successful teaching for African American students*. San Francisco: Jossey-Bass.

Ladson-Billings, G. (1995a). But that's just good teaching! The case for culturally relevant pedagogy. *Theory into Practice, 34*(3), 159-165.

Ladson-Billings, G. (1995b). Toward a theory of a culturally relevant pedagogy. *American Educational Research Journal*, *32*(3), 465-491.

LaFramboise, T. D. (1988). *Cultural and cognitive considerations in the coping of American Indian women in higher education*. Stanford, California: Stanford University, School of Education.

Lambert, L. (2003). From 'savages' to scientists. *Tribal College Journal*, *15*(1), 10-12.

Lee, O. (2003). Equity for culturally and linguistically diverse students in science education: A research agenda. *Teachers College Record*, *105*(3), 465-489.

Lee, O., & Fradd, S. H. (1996). Interactional patterns of linguistically diverse students and teachers: Insights for promoting science learning. *Linguistics and Education: An International Research Journal*, *8*, 269-297.

Lee, O., & Fradd, S. H. (1998). Science for all, including students from non-English language backgrounds. *Educational Researcher*, *27*(3), 12-21.

Lee, O., & Fradd, S. H. (2001). Instructional congruence to promote science learning and literacy development for linguistically diverse students. In D. R. Lavoie & M.-W. Roth (Eds.), *Models for science teacher preparation: Bridging the gap between research and practice*, 109-126. Dordrecht, the Netherlands: Kluwer.

Letiecq, B. L., & Bailey, S. J. (2004). Evaluating from the outside: Conducting cross-cultural evaluation research on an American Indian reservation. *Evaluation Review*, *28*(4), 342-357.

Levy, D. (1992). Bridging tribal, technological worlds. *Science*, *258*, 1231.

Lin, R. (1990). Perception of family background and personal characteristics among Indian college students. *Journal of American Indian Education*, *29*(3) 19-28.

Lin, R. L., LaCounte, D., & Eder, J. (1988). A study of Native American students in a predominantly White college. *Journal of American Indian Education*, *27*(3), 8-15.

Lincoln, Y. S., & Denzin, N. K. (2008). Epilogue: The lions speak. In N. K. Denzin, Y. S. Lincoln, & L. T. Smith (Eds.), *Handbook of critical and indigenous methodologies* (pp. 563-571). Thousand Oaks, CA: Sage.

Lipka, J. & Adams, B. (2002). *Improving Alaska Native rural and urban students' mathematical understanding of perimeter and area.* Unpublished manuscript. Alaska School Research Fund.

Likpa, J., & Adams, B. (2004). Culturally based math education as a way to improve Alaska Native students' math performance (Working Paper No. 20). Athens, OH: Appalachian Center for Learning, Assessment, and Instruction in Mathematics.

Lipka, J., Hogan, M. P., Webster, J. P., Yanez, E., Adams, B., Clark, S., & Lacy, D. (2005). Math in a Cultural Context: Two case studies of a successful culturally based math project. *Anthropology & Education Quarterly, 36*(4), 367-385.

Lipka, J., Sharp, N., Adams, B., & Sharp, F. (2007). Creating a third space for authentic biculturalism: Examples from *Math in a Cultural Context*. *Journal of American Indian Education*, *46*(3), 94-115.

Lomawaima, K. T., & McCarty, T. L. (2002). Reliability, validity, and authenticity in American Indian and Alaska Native research. ERIC Digest (ED470951).

LoRé, R. (1998). *Art as development theory: The spiritual ecology of learning and the affluence of traditional Native American education*. Unpublished dissertation. University of New Mexico.

Lugones, M. (1987). Playfulness, "world"-travelling, and loving perception. *Hypatia*, *2*(2), 3-19.

Lundin, M. (2007). Questions as a tool for bridging science and everyday language games. *Cultural Studies of Science Education*, *2*(1), 265-279.

Mankiller, W. (2008). "What it means to be an indigenous person in the 21st century: A Cherokee woman's perspective." Vine Deloria, Jr. Distinguished Indigenous Scholars Speaker Series, University of Arizona [Lecture series]. Tucson, Arizona. September 30, 2008.

Martin, B. (1997). Culturally responsive teaching: A review of research and literature. ERIC Document. ED 408387.

Matthews, C. E., & Smith, W. S. (1994). Native American related materials in elementary science instruction. *Elementary School Journal*, *97*, 341-358.

McCarthy, C. (1995). The problem with origins: Race and the contrapuntal nature of the educational experience. In P. McLaren & C. Sleeter (Eds.), *Multicultural education, critical pedagogy and the politics of difference* (pp.245-268). Albany, NY: SUNY Press.

McLaren, P. (1997). *Revolutionary multiculturalism: Pedagogies of dissent for the new millennium.* Boulder, Colorado: Westview Press.

Mohanty, C. T. (1991). Under Western eyes: Feminist scholarship and colonial discourses. In C. T. Mohanty, A. Russo, & L. Torres (Eds.), *Third World women and the politics of feminism*. Indianapolis: Indiana University Press.

Mohatt, G., & Erickson, F. (1981). Cultural differences in teaching styles in an Odawa school: A sociolinguistic approach. In H. Trueba, G. Guthrie, & K. Au (Eds.), *Cultural and the bilingual classroom: Studies in classroom ethnography* (pp. 105-119). Rowley, Massachusetts: Newbury.

Moje, E. B., Ciechanowski, K. M., Kramer, K., Ellis, L., Carrillo, R., & Collazo, T. (2004). Working toward third space in content area literacy: An examination of everyday funds of knowledge and Discourse. *Reading Research Quarterly*, *39*(1), 38-70.

Moje, E. B., Collazo, T., Carrillo, R., & Marx, R.W. (2001). “Maestro, what is ‘quality’?”: Language, literacy, and Discourse in project-based science. *Journal of Research in Science Teaching*, *38*(4), 469-698.

Moll, L. C., Amanti, C., Neff, D., & Gonzalez, N. (1992). Funds of knowledge for teaching: Using a qualitative approach to connects homes and classrooms. *Theory into Practice*, *32*(2), 132-141.

Monroe, B. (2002). The internet in Indian country. *Computers and Composition, 19*, 285-296.

Morris, R. W. (1983). *Science and technology education and national development*. Paris: UNESCO.

Mortimer, E. F., & Scott, P. H. (2003). *Meaning making in secondary classrooms*. Maidenhead, UK: Open University Press.

Murfin, B. (1994). African science, African and African-American scientists and the school science curriculum. *School Science and Mathematics*, *94*(2), 96-103.

National Science Board. (2010). Chapter 2: Higher education in science and engineering. In *Science and Engineering Indicators 2010*. Arlington, VA: National Science Foundation (NSB 10-01). Retrieved September 9, 2010 from http://www.nsf.gov/statistics/seind10/c2/c2h.htm.

Nelson-Barber, S., & Estrin, E. T. (1995a). Bringing Native American perspectives to mathematics and science teaching. *Theory into Practice*, *34*(3), 174-185.

Nelson-Barber, S., Estrin, E. T. (1995b). Culturally responsive mathematics and science education for Native students. San Francisco, California: Far West Laboratory for Educational Research and Development.

New London Group. (1996). A pedagogy of multiliteracies: Designing social futures. *Harvard Educational Review*, *66*, 60-92.

Nieto, S. (1998). *With light in their eyes: Creating multicultural learning communities*. New York: Teachers College Press.

Ogawa, M. (1995). Science education in a multiscience perspective. *Science Education*, *79*(5), 583-593.

Ogbu, J. U. (1978). *Minority education and caste: The American system in cross-cultural perspective*. New York: Academic Press.

Ogunniyi, M. B. (1988). Adapting western science to traditional African culture. *International Journal of Science Education*, *10*(1), 1-9.

Omizo, M. M., & Omizo, S. A. (1989). Art activities to improve self-esteem among Native Hawaiian children. *Journal of Humanistic Education and Development*, *27*(4), 167-175.

Omizo, M. M., Omizo, S. A., & Kitaoka, S. K. (1998). Guided affective and cognitive imagery to enhance self-esteem among Hawaiian children. *Journal of Multicultural Counseling and Development*, *26*(1), 52-62.

Ongtooguk, P. (2000). Aspects of traditional Inupiat education. *Sharing Our Pathways: A newsletter of the Alaska Rural Systemic Initiative*, *5*(4), 8-12.

Patchen, T., & Cox-Petersen, A. (2008). Constructing cultural relevance in science: A case study of two elementary teachers. *Science Education*, *92*(6), 994-1014.

Pavel, M.; Inglebret, E., & Banks, S. (2001). Tribal colleges and universities in an era of dynamic development. *Peabody Journal of Education, 76*(1), 50-72.

Pewewardy, C. (2001). Indigenous consciousness, education and science: Issues of perception and language. In K. James (Ed.), *Science and Native American communities: Legacies of pain, visions of promise*, (pp. 16-21). Lincoln & London: University of Nebraska Press.

Phelan, P., Davidson, A., & Cao, H. (1991). Students' multiple worlds: Negotiating the boundaries of family, peer, and school cultures. *Anthropology and Education Quarterly, 22*(3), 224-250.

Phuntsog, N. (1998). The magic of culturally responsive pedagogy: In search of the genie's lamp in multicultural education. Paper presented at the Annual Meeting of the American Educational Research Association, San Diego, CA, April 13-17, 1998.

Poodry, C. (2001). How to get what Indian communities need from science. In K. James (Ed.), *Science and Native American communities: Legacies of pain, visions of promise*, (pp. 29-35). Lincoln & London: University of Nebraska Press.

Posner, G., Strike, K., Hewson, P., & Gertzoy, W. (1982). Accommodation of scientific conception: Toward a theory of conceptual change. *Science Education*, *66*, 211–227.

Rains, F. V., Archibald, J. A., & Deyhle, D. (2000). Introduction: Through our eyes and in our own words. *Qualitative Studies in Education*, *13*(4), 337-342.

Reyhner, J. (1992). Bilingual education. In Reyhner, J. (Ed.), *Teaching American Indian students* (pp. 59-77), Norman, OK: University of Oklahoma Press.

Reyhner, J. (2002). American Indian / Alaska Native education: An overview. *American Indian Education.* Retrieved 5/08/2004 from http://jan.ucc.nau.edu/~jar/AIE/Ind_Ed.html.

Reyhner, J., & Dodd, J. (1995, January). Factors affecting the retention of American Indian and Alaska Native students in higher education. Paper presented at the first annual Expanding Minority Opportunities national conference, Tempe, AZ.

Reyhner, J., & Jacobs, D. (2002). Preparing teachers of American Indian and Alaska Native students. *Action in Teacher Education, 24*(2), 85-93.

Richardson, L., & St. Pierre, E. A. (2005). Writing: A method of inquiry. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 959-978). Thousand Oaks, CA: Sage.

Riggs, E. M. (2005). Field-based education and indigenous knowledge: Essential components of geoscience education for Native American communities. *Science Education*, *89*(2), 296-313. Retrieved 7/19/2012 from http://www.duluth.umn.edu/~bmunson/Courses/Educ5560/readings/Riggs-Indigenous.pdf; reproduction pp. 1-18.

Rindone, P. (1988). Achievement motivation and academic achievement of Native American students. *Journal of American Indian Education*, *28*(1), 1-8.

Rodriguez, Y. E. & Sjostrom, B. R. (1996). Strategies for teaching in a culturally responsive manner. Paper presented at the Annual Meeting of the American Association of Colleges for Teacher Education, Chicago, IL, February 21-24, 1996.

Rosebery, A. S., Warren, B., & Conant, F. R. (1992). Appropriating scientific discourse: Findings from language minority classrooms. *The Journal of the Learning Sciences, 21*, 61-94.

Running Wolf, P. & Rickard, J. A. (2003). Talking circles: A Native American approach to experiential learning. *Journal of Multicultural Counseling and Development, 31*, 39-43.

Schmidtke, C. (2009). "That's what really helped me was their teaching": Instructor impact on the retention of American Indian students at a two-year technical college. *Journal of Industrial Teacher Education*, *46*(1), 48-80.

Scott, P. H., Mortimer, E. F., & Aguiar, O. G. (2006). The tension between authoritative and dialogic discourse: A fundamental characteristic of meaning making interactions in high school science lessons. *Science Education*, *90*(4), 605-631.

Simonelli, R. (1994). Toward a sustainable science. *Winds of Change*, *8*(2), 36-37.

Singham, M. (2007). Death to the syllabus! *Liberal Education*, *93*(4). Reprinted by the Tomorrow's Professor electronic mailing list, archived at http://tomprofblog.mit.edu/2007/11/.

Smith, L. T. (1999). *Deolonizing methodologies: Research and indigenous peoples*. Dunedin, New Zealand: University of Otago Press.

Smith, L. T. (2005). On tricky ground: Researching the Native in the age of uncertainty. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 85-107). Thousand Oaks, CA: Sage.

Smolicz, J. H. & Nunan, E. E. (1975). The philosophical and sociological foundations of science education: The demythologizing of school science. *Studies in Science Education*, *2*, 101-143.

Snively, G. (1986). *Sea of images: A study of the relationships amongst students' orientations, beliefs and science instruction*. Unpublished Ed.D. dissertation, University of British Columbia, Vancouver.

Snively, G. (1995). Bridging traditional science and Western science in the multicultural classroom. In G. Snively & A. Mackinnon (Eds.), *Thinking globally about mathematics and science education* (pp. 53-75). Vancouver, Canada: University of British Columbia Press.

Snively, G., & Corsiglia, J. (1998). Discovering Indigenous science: Implications for science education. Paper presented at the 71st Annual Meeting of the National Association for Research in Science Teaching, San Diego, California, April 19-22, 1998.

Soja, E. W. (1996). *Thirdspace: Journeys to Los Angeles and other real-and-imagined places*. Malden, MA: Blackwell.

Spivak, G. (1988). Can the subaltern speak? In C. Nelson & L. Grossberg (Eds.), *Marxism and the interpretation of culture* (pp. 271-313). Bassingstoke, UK: Macmillan.

Stairs, A. (1995). Learning processes and teaching roles in Native education: Cultural base and cultural brokerage. In M. Battiste & J. Barman (eds.), *First Nations education in Canade: The circle unfolds* (pp. 139-153). Vancouver, Canada: University of British Columbia Press.

Stake, R. E. (2005). Qualitative case studies. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 443-466). Thousand Oaks, CA: Sage.

Steinhauer, E. (2002). Thoughts on an Indigenous research methodology. *Canadian Journal of Native Education*, *26*(2), 69-81.

Stephens, S. (2001). *Handbook for culturally responsive science curriculum*. Alaska Science Consortium & the Alaska Native Knowledge Network.

Sutherland, D. (2005). Resiliency and collateral learning in science in some students of Cree ancestry. *Science Education*, *89*(4), 595-613.

Sutherland, D., & Dennick, R. (2002). Exploring the nature of culture, language, and the perception of science. *International Journal of Science Education*, *24*(1), 1-25.

Swadener, B. B. & Mutua, K. (2008). Decolonizing performances: Deconstructing the global postcolonial. In N. K. Denzin, Y. S. Lincoln, & L. T. Smith (Eds.), *Handbook of critical and indigenous methodologies* (pp. 31-43). Thousand Oaks, CA: Sage.

Swisher, K. & Deyhle, D. (1992). Adapting instruction to culture. In J. D. Reyhner (Ed.), *Teaching American Indian Students* (pp. 81-95). Norman, Oklahoma: University of Oklahoma Press.

Tafoya, T. (1995). Finding harmony: Balancing traditional values with Western science in therapy. *Canadian Journal of Native Education*, *21* (Supplement), p. 7-27.

Tate, D. S., & Schwartz, C. L. (1993). Increasing the retention of American Indian students in professional programs in higher education. *Journal of American Indian Education*, *33*(1), 21-31.

Tharp, R. (1982). The effective instruction of comprehension: Results and description of the Kamehameha Early Education Program. *Reading Research Quarterly*, *71*(4), 503-527.

Thayer-Bacon, B. (1997). The nurturing of a relational epistemology. *Educational Theory*, *47*(2), 239-260.

Thomas, R. (2005). Honouring the oral traditions of my ancestors through storytelling. In Brown & Strega (eds). *Research as resistance – Critical, Indigenous and anti-oppressive approaches* (pp. 237-254). Toronto: Canadian Scholars Press.

Tohono O'odham Community College. (2002). Integration of Tohono O'odham Himdag. Accessed 10 September, 2010 from http://www.tocc.cc.az.us/himdag_policy.htm.

Tohono O'odham Community College. (2010). About TOCC: TOCC history. Accessed 8 July, 2010 from http://tocc.cc.az.us/history.htm.

Tohono O'odham Community College. (n.d.). About TOCC: TOCC history; Institutional Profile. Accessed 8 July, 2010 from http://tocc.cc.az.us/.

Trout, J. (2005). Re-membering mathematics: The effect of culturally relevant math history lessons on students' attitudes. In L. P. McCoy (Ed.), *Studies in teaching 2005 research digest: Research projects presented at Annual Research Forum*, (pp. 116-120). Wake Forest University.

Trujillo, O. V., Figueira, A., Viri, D., & Manuelito, K. (2003). Native educators interface with culture and language in schooling. Paper presented at the Annual Meeting of the American Educational Research Association, Chicago, IL, April 21-25, 2003.

Van Hamme, L. (1996). American Indian Cultures and the Classroom. *Journal of American Indian Education, 35*(4), 21-36.

Vélez, W. Y. (n.d.) SACNAS Biography Project. In *SACNAS*. Retrieved October 19, 2008 from http://www.sacnas.org/biography/.

Vélez-Ibáñez, C. G., & Greenberg, J. (1992). Formation and transformation of funds of knowledge among U.S.-Mexican households. *Anthropology and Education Quarterly*, *23*(4), p. 313-335.

Villegas, A. (1988). School failure and cultural mismatch: Another view. *Urban Review, 20*, 253-265.

Villegas, A. M. (1991). *Culturally Responsive Pedagogy for the 1990s and Beyond*. Princeton, NJ: ETS.

Vogt, L., Jordan, C., & Tharp, R. (1987). Explaining school failure, producing school success: Two cases. *Anthropology and Education Quarterly*, *18*, 276-286.

Voorhees, R.A. (2003). Characteristics of tribal college and university faculty. Report submitted to the American Indian College Fund. Downloaded 22 July, 2010 from http://www.collegefund.org/downloads/TCUFacultyPaper11.pdf.

Vygotsky, L. S. (1934). Thinking and speech. In R. W. Rieber & A. S. Carton (Eds.) and N. Minich (trans.), *The Collected Works of L. S. Vygotsky*. New York: Plenum Press (1987).

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes.* Cambridge, MA: Harvard University Press.

Vygotsky, L. S. (1981). The genesis of higher mental functions. In J. V. Wertsch (Ed.), *The concept of activity in Soviet psychology* (pp. 144–188). Armonk, NY: Sharpe.

Wachtel, L. A. (1995). Headlong into inside out: The process of becoming an effective multicultural science teacher. Paper presented at the Annual Meeting of the American Educational Research Association, San Francisco, CA, April 18-22, 1995. ERIC Document. ED390826.

Warren, B., Ballenger, C., Ogonowski, M., Rosebery, A., & Hudicourt-Barnes, J. (2001). Rethinking diversity in learning science: The logic of everyday language. *Journal of Research in Science Teaching*, *38*(5), 529-552.

Weber-Pillwax, C. (2003). *Identity formation and consciousness with reference to Northern Alberta Cree and Metis Indigenous peoples.* (Order No. NQ82179, University of Alberta (Canada)). *ProQuest Dissertations and Theses,* , 201-201 p. Retrieved from http://ezproxy.library.arizona.edu/login?url=http://search.proquest.com/docview/305259512?accountid=8360. (prod.academic_MSTAR_305259512).

Westby, C., Dezela, J., Fradd, S. H., & Lee, O. (1999). Learning to do science: Influences of language and culture. *Communications Disorders Quarterly*, *21*(1), 50-64.

Wickman, P., & Östman, L. (2002). Learning as discourse change: A sociocultural mechanism. *Science Education*, *86*(5), 601-623.

Willeto, A. A. A. (1999). Navajo culture and family influences on academic success: Traditionalism is not a significant predictor of achievement among young Navajos. *Journal of American Indian Education*, *38*(2), 1-24.

Wilson, P. (1997). Key factors in the performance and achievement of minority students at the University of Alaska-Fairbanks. *American Indian Quarterly, 21*(3), 535-544.

Wilson, S. (2008). *Research is ceremony: Indigenous research methods*. Black Point, N.S: Fernwood.

Winzer, M., & Mazurek, K. (1998). *Special education in multicultural contexts*. New York: Prentice Hall.

Wright, B. (1992). *American Indian and Alaska Native higher education: Toward a new century of academic achievement and cultural integrity.* Commissioned paper, The Indian Nations at Risk Task Force, U.S. Department of Education.

Wright, B., & Tierney, W. G. (1991). American Indians in higher education. *Change*, *23*(2), 11-18.

Zacharias, Z., & Calabrese Barton, A. (2003). Urban middle-school students' attitudes towards a defined science. *Science Education*, *87*, 1-27.

Zepeda, O. (2001). Rebuilding languages to revitalize communities and cultures. In James, K. (ed.), *Science and Native American communities* (pp. 57-62). Lincoln & London: University of Nebraska Press.