Culturally Relevant Science Education as a Contextualizing Strategy: Supporting Mexican Nahua Students to Understand Core ideas of Western Science

by

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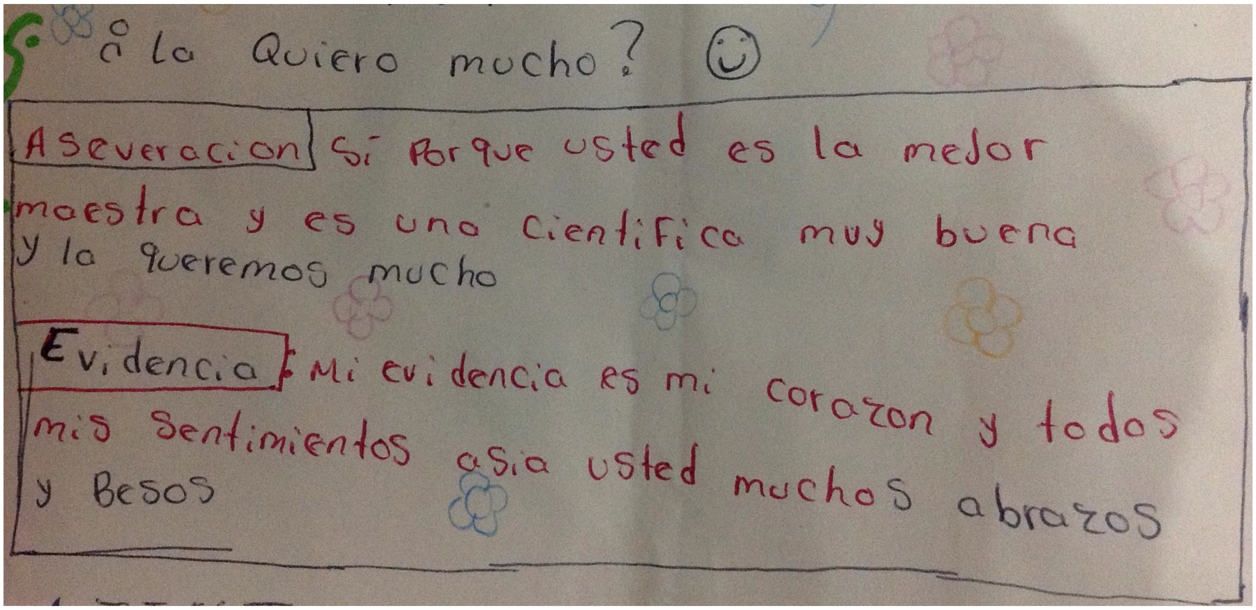
Many mentors, friends, and family members made this dissertation possible by constantly supporting me, but no one deserves more gratitude than the students of 1º de secundaria in the Escuela Secundaria Técnica Industrial #153 (Tequila, Veracruz) and their science teacher Marina. These students and their science teacher were incredibly generous in sharing with me their views of the world, their enthusiasm for learning, their time, and their affection. They were open to letting me try my ideas in the classroom, but they were also my best teachers, helping me crystalize what it really means for me to be a science educator committed to social justice. They helped me to understand that when I write a research project, or go into the classroom to collect data, it is not about me and a possible future publication. It is about them. It is their lives I am participating in and writing about. They are not data and data sources. They are young individuals with unique perspectives whose passion for learning and for change ignites my own. The students who participated in this dissertation were my students and my teachers. I wanted them to learn that they could use what they learned in the science classroom with autonomy and agency in ways that were true to their own identities and goals. To my surprise, some of them went beyond my expectations, using science concepts and practices in ways that were really meaningful for them. I want to share one of those instances here. In the image below, is part of a letter that a student wrote to me after completing the unit. I insisted so much on using evidence and worked with students so intensively on constructing evidence-based scientific explanations that this

student thought of that format as ideal for me to understand her emotions. She was using what she learned in the science classroom to reach out to me, a foreigner, a Westerner, a science teacher, and get her idea across.



The question she posed was “Do I love you?”, her claim was “yes because you are the best teacher and a very good scientist and we love you very much”. The evidence she provided to back up her claim was “my evidence is my heart and all the feelings towards you many hugs and Kisses” These gestures of affection and demonstrations of learning and inventiveness were my fuel to conduct and complete this dissertation. All the pages in this dissertation were possible because of them; all that I learned they helped me learn, and therefore my deepest gratitude is for them.

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PREFACE

"One or two generations from now, the 20th century and the early part of the 21st century will not be remembered for wars or technological innovations. It will be remembered as the era when we stood by and either actively endorsed or passively accepted the massive destruction of both the biological and cultural diversity of this planet.

It's interesting that genocide, physical extermination of a people, is universally condemned. Yet ethnocide, the destruction of a people's way of life, is not only not condemned; in many parts of the world, it is encouraged and advocated as appropriate policy. Wherever one goes, one sees this clash of cultures, this clash of history."

Wade Davis, 2001.

I do not believe in a science education that perpetrates ethnocide.

This dissertation is a testament to this commitment.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

In this dissertation I proposed, enacted, and evaluated a process of culturally relevant curricular contextualization aimed to provide access to science to ethnic minority middle school students, in this case Nahua students from Veracruz, Mexico. Because prior knowledge is the main input for the contextualization process, this dissertation pushes the boundaries of how we approach students' prior knowledge. I propose that cultural cognition, socialization, and cultural narratives play a central role in shaping students' prior knowledge. Not accounting for these dimensions of prior knowledge when designing curriculum and instruction leaves marginalized students alone in navigating the differences between their culture and home language and the culture and language of school. Against this backdrop, this study takes culture and socialization into account by using multiples sources (cognitive tasks to explore teleology and essentialism, ethnographic observation of students' community and classroom, and interviews with students and adults in students' communities) to develop eight principles of contextualization, aligned with the scholarship in Culturally Relevant Pedagogy and Indigenous Education. The significance of this study lies not only in providing a set of principles and concrete examples for contextualization of science curricula, but also in providing an empirically developed process of curricular contextualization that integrates culture and cognition, socialization, experiences of border crossing, and a social justice approach. The curricular unit that was contextualized using this approach resulted in students' learning gains, development of a positive ethnic identity, agency to use both their own traditional knowledge and Western science knowledge in a context-dependent manner, and imagining possible

futures in science. This dissertation may be one of the first studies in which border crossing is documented from the point of view of the students, and in the context of learning specific core concepts of Western science with a contextualized curriculum. The process of contextualization and the categories of border crossing presented in this dissertation can be of great value to science teachers and curriculum designers willing to engage in culturally relevant pedagogies, as they will have a better idea of the various experiences their students may have and anticipate appropriate strategies to support all students' learning.

CHAPTER 1: INTRODUCTION

This dissertation examines curricular contextualization of science materials from the perspective of Culturally Relevant Pedagogy, as a way to increase access to science education for Mexican Nahua adolescents. Nahua indigenous communities in Mexico see education as a fundamental component for achieving improvements in their quality of life, and for accessing more ample political participation that ultimately will translate into improved quality of health and education services for their people. However, one aspect of their public school education, namely science education, has historically undermined their worldviews, thus threatening their existence as a group and creating tension between their culture and school science. This tension is comparable to that of indigenous groups in New Zealand, Canada, and the United States, where research has demonstrated that learning environments that force students to sacrifice their cultural identity actually impede science learning, and therefore access to an education that fosters scientific literacy (Agbo, 2004; Cajete, 1994; Castagno & Brayboy, 2008; McCarty, 2012; Pewewardy, 2003; McKinley, 2007). These studies highlight the urgency of identifying educational strategies that facilitate indigenous students' access to relevant science education. One possible way to provide this access involves contextualizing quality science curricular materials to achieve relevance for students whose culture is not the dominant Western culture. Research suggests that contextualization of curriculum and instruction fosters students' learning of science (Rivet & Krajcik, 2008). To extend this work, in this study the issue of curriculum contextualization for indigenous students will be investigated through the main question: "What does it mean to contextualize science curricula in a culturally relevant manner for indigenous middle school students so that learning of challenging concepts is facilitated?”

Contextualizing science curricular materials to become culturally relevant for indigenous students has two important potential outcomes. For one, it may decrease the high attrition among indigenous adolescents during middle school in Mexico, and it can narrow the achievement gap between indigenous and urban students. If Culturally Relevant Science Education (CRSE) is provided to indigenous students, wider opportunities become available for them to compete equally with non-indigenous people to access higher education, and to fully participate in the economy, politics, and culture of their National contexts. Further, CRSE can foster scientific literacy among indigenous students.

Central to scientific literacy is developing competency to participate in conversations and debates about social and environmental problems, which provides agentic room to maneuver in decision-making at the community and national levels, which is a primary goal of indigenous groups worldwide (Roth & Désautels, 2002; Roth, 2009). Indigenous groups have been historically excluded from experiencing a CRSE that leads to scientific literacy, even in countries such as Mexico with legislation affirming the right of indigenous peoples to quality education. In fact, no programs in Mexico have supported indigenous communities striving to become scientifically literate, thus increasing the social injustices these communities face.

To be scientifically literate, individuals must understand core organizational principles of the scientific disciplines (NRC, 2009, 2012). In biology, one of the core concepts is evolution through natural selection. This concept forms the foundation for understanding applications of biology such as biotechnology, bioengineering, medical advances, and environmental science, all crucial in the 21st century society (Southerland & Nadelson, 2012). Because understanding natural selection has an important effect on becoming biologically literate, this study focuses on teaching this concept to Nahua students by contextualizing a high quality curricular unit on natural selection. This focus dovetails with the rich Traditional Indigenous Knowledge (TIK) of the Nahuas regarding the natural world.

To better understand the role that students' culture plays in curricular contextualization and students' experiences with culturally relevant science materials, two sub-research questions are posed in this study:

- Do Nahua students exhibit teleological and essentialist reasoning patterns different from the normative views of Western science? If so, how do these reasoning patterns influence the learning of the Western science concepts of inheritance and natural selection?
- How do students cross borders between their culture and Western science culture when learning within a contextualized unit on inheritance and natural selection?

Regarding the first question, this study hypothesized that Nahua TIK and reasoning would likely be different from the normative views of Western science. Research has shown this to be the case for multiple cultures worldwide, because prevalent reasoning patterns, such as essentialism and teleological thinking, underlie common alternative conceptions regarding the living world. These reasoning patterns are presented in the literature as obstacles for students to understand natural selection (Kelemen, 2009, 2012; Gelman & Rhodes, 2012; Shtulman & Schulz 2008; Shtulman & Calabi, 2012). However, reasoning patterns and alternative conceptions about natural selection among Nahua students has yet to be explored.

Regarding the second question, this study hypothesizes that a border crossing approach to learning science will facilitate students' science learning by bridging students' culture and the culture of Western science. Research has shown that when science is taught in ways that demonstrate respect for students' cultures and communities, using their traditional knowledge as a valuable resource for learning, students develop more positive ethnic identities and interest in learning at school (Agbo, 2004; Bang & Medin, 2010; Barton et al., 2013; Castagno & Brayboy, 2008; Klug & Whitfield, 2003; McCarty, 2012.)

The hypothesized differences between the Nahua's knowledge and reasoning about the natural world and Western science provide a unique opportunity to test the effects of a contextualized curriculum on students' learning gains and experiences of border crossing while learning science. That is, students' experiences learning concepts that are not necessarily aligned with their TIK (e.g. natural selection) in a way that acknowledges culture-specific reasoning patterns, worldviews and communities' ways of interacting, while becoming engaged in thinking critically about socio-scientific issues.

The two sub-research questions and corresponding hypotheses were investigated by contextualizing a curricular biology unit on inheritance and natural selection for 7th grade students and enacting it in a Nahua School in the village of Tequila (Veracruz, Mexico). Investigating these questions allowed for the creation of a process of contextualization for science curricular materials, focused on providing learning opportunities for ethnic minority students. Using this process as a guideline for contextualizing curricular materials will allow access to quality science education and scientific literacy for indigenous and other marginalized students.

1.1. Curricular Contextualization from the Perspective of Culturally Relevant Pedagogy

This dissertation examines curricular contextualization of science materials from the perspective of Culturally Relevant Pedagogy as a way to increase access to science education for Mexican Nahua adolescents. Curricular contextualization is understood in this study as the process of adapting existing quality curricular materials in order to facilitate students' understanding of challenging science concepts by leveraging their prior knowledge and experiences (Rivet & Krajcik, 2008). Because prior knowledge is the main input for the contextualization process, I push the boundaries of how we approach students' prior knowledge. Traditionally, learning scientists have pursued explanations about how students learn by using the framework of prior knowledge as cohesive mental schemas (Hewson & Hewson, 1983; Treagust & Duit, 2008; Vosniadou, 2002) or as fragmented highly contextual ideas (diSessa, 2006); but rarely they have fully accounted for the learners' social, cultural, and historical contexts. Therefore, in this dissertation I am not taking a stance whether students' prior knowledge is cohesive or fragmented, but I have taken an approach that contributes to the two perspectives by aiming to understand the multiple sources that shape students' prior knowledge (fragmented or not). By exploring the different factors that influence students' prior knowledge it was possible to contextualize a biology unit on inheritance and natural selection for middle school that responded to the learners' worldviews in their social, cultural, and historical context.

I propose that contextualization can be culturally relevant by accounting not only for the ideas and experiences that students bring to the classroom, but for the culturally-based psychological patterns of reasoning that underlie those ideas, and for the cultural practices, traditions, and societal structures that render those ideas meaningful for students. Moreover, from a socio-constructivist perspective, I propose that for science curricula to be culturally relevant for students it must bridge students' cultures and Western science culture, so that students' cultures are respected and valued as resources for learning.

This interdisciplinary understanding of Culturally Relevant Science Education was examined by contextualizing a curricular unit on inheritance and natural selection and enacting it in two 7th grade classrooms of an indigenous Nahua school in Veracruz, Mexico. Through a combined approach of cultural cognition and ethnographic observation I collected information about Nahua students' cultural and social context, as well as their cultural narratives about plants and animals, and their school knowledge about inheritance and natural selection. These multiple sources of information allowed me to conceptualize eight contextualization principles that guided activity design and scaffolds included in the already validated unit on inheritance and natural selection to make it specifically relevant for Nahua students.

These eight principles were tested during the enactment of the unit through a combination of pre- and post-interviews about culturally based reasoning patterns influencing the understanding of natural selection (teleology and essentialism), pre- and post-tests on content knowledge of inheritance and natural selection, and an ethnographic analysis of students' experiences through the enactment of the unit. This process—from the data collection procedure that informed the contextualization principles to the students' experiences and learning outcomes— was documented in order to create a process of curricular contextualization that is culturally relevant and can be used to contextualize other science materials.

This proposed contextualization process allows for a better understanding of how to incorporate a cultural and social dimension into science curricular materials and instruction, and the effects of this approach in how ethnic minority students experience science learning. The analysis throughout this dissertation focuses on identifying the curricular features that trigger students' cognitive engagement while supporting them in becoming competent in both their own culture and in the culture of Western science.

1.2. Nahua People and the Mexican Educational System

The Nahua are the largest ethnic minority group in Mexico. At 1.5 million people, they represent 1.3 percent of Mexico's total population and 24 percent of the indigenous population. The Nahua find themselves suffering under profound social inequities. This dissertation is concerned with the prospect that schools often reproduce these inequities by designing and enacting curricular materials and pedagogical strategies that portray the mestizo population's lifestyles, values, dispositions and symbols as the "norm" that indigenous students have to learn to succeed (Rodríguez López & Hasler Hangert, 2000; Gómez Lara, 2011). Within this context, science education for indigenous schools is designed by the different Mexican States based on policies stating that Western science is the only truth that should be taught at schools to overcome the populace's ignorance (Mexican Constitution, Article 3). Consequently, indigenous communities experience limited involvement in the science education of their children and youth, and are excluded from socio-scientific debates that affect their communities directly. This study is the first initiative designed specifically to foster scientific literacy among indigenous students in the middle school level that has the support of the Veracruz State government and the Nahua people.

1.3. Relevance of Scientific Literacy for Nahua Students

The Culturally Relevant approach to Science Education of this dissertation aims to foster scientific literacy among Nahua students. Central to scientific literacy is developing competency to participate in conversations and debates about social and environmental problems. This competency provides agentic room to maneuver in decision-making at the community and national levels, a primary goal of indigenous groups worldwide (Roth & Désautels, 2002; Roth, 2009). Despite this goal, no programs in Mexico have supported indigenous communities striving to become scientifically literate, thus increasing the social injustices they face.

Students see their worldviews undermined in the name of science (McKinley, 2007). As per my own observations in science classrooms in the State of Veracruz, indigenous students' traditional practices and narratives are called "fantasies" or "witchcraft" and are proven wrong with the scientific knowledge the teacher imparts.

These school practices create tension between students' culture and school science. Research has demonstrated that tensions like these lead to learning environments that force students to sacrifice their cultural identity, thus impeding learning and access to an education that fosters scientific literacy (McKinley, 2007).

Scientific literacy has been shown to foster higher order thinking skills and to develop socio-scientific decision-making skills fundamental to higher education access and more ample political participation (National Research Council, 2011). Therefore, science learning creates wider opportunities for indigenous students to compete equally with non-indigenous people in efforts to access higher education, and to fully participate in the economy, politics, and culture of their National contexts, from which they have been historically excluded (Rodríguez López & Hasler Hangert, 2000). Access to higher education in Mexico and other Latin American countries requires students to take tests where their knowledge of Western science is measured. Currently, only 1 percent of indigenous youth access higher education. Providing a model of curricular contextualization based on Culturally Relevant Pedagogy to be applied across indigenous schools in Mexico has the potential to increase indigenous students' access to quality science education, potentially increasing their participation at the higher education level. In this context, it is urgent to identify educational strategies that facilitate indigenous students' access to scientific literacy without devaluing their own cultures.

The rich knowledge of the Nahua culture about the natural world makes biology curricula a fertile starting point to foster scientific literacy from a Culturally Relevant perspective. Indigenous students who live in rural Mexico tend to have a rich knowledge of the natural world that is shared among the members of their communities. This knowledge can function as a substrate for science instruction in which students learn to cross borders between the ways in which Western science and Nahua culture explore and explains the natural world. This way, students will experience a biology education in which their cultural knowledge is valued.

Within the discipline of biology, natural selection is considered a gateway concept toward scientific literacy (NRC, 2009, 2012). This concept is the foundation for understanding biology applications such as biotechnology, bioengineering, medical advances, and environmental science, all crucial in the 21st century society (Southerland & Nadelson, 2012). Because understanding natural selection has an important effect on becoming biologically literate, this study focuses on teaching this concept to Nahua students by redesigning and contextualizing a high quality curricular unit on natural selection.

Research suggests that contextualization of curriculum and instruction fosters students' learning of science (Rivet & Krajcik, 2008). However, there is scant published research that portrays contextualized science curricular materials and instruction that is culturally relevant for indigenous students and drawn from Science Education research and from Developmental Psychology and Cultural Studies of Education. The multidisciplinary perspective of this study favors the creation of a process of contextualization for science curricular materials focused on providing learning opportunities to ethnic minority students. Using this model as a guideline for contextualizing curricular materials will allow other indigenous and ethnic minority communities to gain access to quality science education and scientific literacy.

In the next three chapters, I frame this study in terms of the research literature and a mixed methods research design. I then move on to a sequential analysis of my data, starting with the empirical process of contextualization and followed by the effects of the unit on students' reasoning patterns (teleology and essentialism) and on their experiences of border crossing between cultures while learning science. In Chapter 2 I review research literature related to contextualization of science materials and instruction from the lens of Culturally Relevant Science Education, as well as the significance of learning the concept of natural selection and the factors that influence its learning. In Chapter 3, I present my research design, including methods of analysis for this study and corresponding questions. Through Chapter 4, I offer a detailed description of how I used multiples sources of data to conceptualize the eight contextualization principles and how they led to the design of new activities and scaffolds. Representative examples of these new activities and scaffolds are included in this chapter. I present the results of enacting this contextualized unit in chapters 5 and 6, where I focus on the effects of the unit on students' learning and experiences. I did not analyze the teaching strategies that were part of the enactment of the unit as it goes beyond the scope of this study, centered exclusively on curriculum design and its effects on students' experiences. Finally, in Chapter 6 I offer conclusions for the study as I summarize the key findings, and discuss implications for research and practice.

CHAPTER 2: REVIEW OF THE LITERATURE

2.1. Culturally Relevant Science Education and Contextualization

Recently, in the field of science education, efforts have been underway to design science-learning environments that foster high academic achievement in language and culture minority students (Lee et al., 2006). A growing body of research in Culturally Relevant science-learning environments has focused on understanding the characteristics of these types of learning environments (Lee, Butler, & Tippins, 2007; Lee, 2003). According to Johnson (2011), "Researchers agree that culturally relevant science instruction harnessing knowledge, experiences, and cultures of diverse populations are crucial components of reforming science education." Culturally relevant pedagogy enriches the strands of scientific proficiency highlighted in Taking Science to School (NRC, 2007), emphasizing an equity perspective. However, achieving equity in science education continues to be a challenge, highlighting the need for additional information and experiences about the features of culturally relevant science-learning environments (Calabrese-Barton & Lee, 2006; Lee et al., 2006).

In the context of this study, "culture" is composed of historically transmitted patterns of behavior, and shared cognitive frames of meaning, by which a group develops its knowledge and attitudes towards the world (Geertz, 1973). In this context, Western modern science is a culture, different from the traditional culture of indigenous groups in Latin America. The term "indigenous", in turn, is defined here as groups of people who claim the earliest connection to land bases in the countries where they currently live, before colonization, and who have maintained distinct, nuanced cultural and social organizing principles (Castagno & Bradboy, 2008). Mexican indigenous peoples are recognized by the mainstream society in terms of their ability to speak a heritage language different from the Spanish of colonization. However, Nahua individuals are both self-identified and are recognized by members of their community as indigenous regardless of their heritage language domain.

Indigenous adolescents in this study who have maintained cultures distinct from the mainstream cultures where they live require educations that prepare them to succeed in both cultures. In Mexico, the United States, and New Zealand, indigenous students perform worse than their mestizo urban peers (members of the dominant cultural group), partly because their traditional culture is at odds with the culture and expectations of schools (Castagno & Bradboy, 2008). This stands in contrast to other scholars who attribute this achievement gap to the fact that learning science for indigenous students is the equivalent of assimilation into a foreign culture which the students reject, causing their alienation from Western science and community matters related to science and technology (Aikenhead, 2002). This alienation has been perpetuated by the schools and school systems that serve indigenous students. In fact, the pedagogies that have been historically used to teach science to indigenous students negate their lived experience and subjective understanding of the world, thus transforming schools into instruments that reproduce the racial inequities in a society (O'Loughlin, 1992; Aikenhead, 2002).

In response to this mismatch in cultures, and the social injustices faced by indigenous groups and other ethnic minorities around the world, Culturally Relevant Pedagogy (Ladson-Billings, 1995) and Cross-Cultural Science Education (Aikenhead, 2002) have offered useful guidelines to design science learning environments that respect students' cultures, help minority culture students learn that modern Western is one way another culture explains the world. These approaches empower students to use their knowledge of science as a tool for socio-political action (Roth & Désautels, 2002).

Culturally Relevant Pedagogy is defined by Ladson-Billings (1995, p.160) as

> a pedagogy of opposition not unlike critical pedagogy but specifically committed to collective, not merely individual, empowerment. Culturally relevant pedagogy rests on three criteria or propositions: (a) Students must experience academic success; (b) students must develop and/or maintain cultural competence; and (c) students must develop a critical consciousness through which they challenge the status quo of the current social order.

Within this framework, teachers attend to students' academic needs and use the knowledge they have of their students' culture as a vehicle for learning and motivating their students to achieve academic excellence. Furthermore, in culturally relevant learning environments, parents and elders are involved in the classroom; students learn from one anothers' parents, thus affirming their cultural knowledge alongside the concepts and skills included in the school curricula. This parental and elder involvement is especially important for indigenous students as they learn to "translate" science in order to communicate with their community members. Students therefore gain experience with code-switching between the culture of Western science and their own culture. Finally, the aspect of culturally relevant pedagogy aimed at developing a critical sociopolitical conscience in students will benefit Mexican Nahua students because it will invite reflection on social issues (e.g., the implications of buying new seeds from biotechnology companies as opposed to the seeds traditionally used in their communities, or why being biologically illiterate limits indigenous students' access higher education). This aspect is compatible with two of the core practices in Western science: engaging in argumentation from evidence, and obtaining, evaluating, and communicating information (NRC, 2012). This consistency emerges because the science classroom can become a place for preparing indigenous students to use evidence to critique socio-scientific issues that contribute to social inequities.

An alternative perspective, Cross-Cultural Science Education, offers more insight into the second proposition of culturally relevant pedagogy (students must develop and/or maintain cultural competence). Cross-Cultural Science Education focuses on learning science to enable participation in the cultures of power, while constructing meaning of science concepts and practices from a cultural perspective. In order to achieve these goals, Cross-Cultural Science Education rests in five principles: 1)Western modern science is a culture itself (a subculture of Mexican society in this study); 2) the identities of Nahua students may be at odds with the culture of Western science; 3) the science classroom is a subculture of the school culture; 4) indigenous students will experience a change in culture when moving from their world vision to the world of Western science; and 5) learning science is a cross-cultural experience for indigenous students (Aikenhead, 2002). By following these principles, teachers create learning environments where students come to know a new culture of science that has its own language, beliefs, conventions, values, expectations, and technologies. As part of this process, students must reflect on their own cultural understandings of the natural world, learn the ways of knowing in Western science and other indigenous cultures, and be introduced to the language, beliefs, conventions, values, expectations, and technologies of Western science (Aikenhead, 2002).

In this study, questions and cases will be introduced to the IQWST biology unit that will prompt students to reflect about their cultural understanding of the biological world, and about how Western science has explained the diversity and changes of life forms. If possible, the questions and cases will also help indigenous students learn how other indigenous cultures explain the biological world. In other words, the IQWST unit used in this study will be contextualized based on the guiding principles of Culturally

Relevant Pedagogy and Cross-Cultural Science Education, so that it is relevant to Nahua students. Contextualizing curricular materials motivate students' learning of science concepts and practices by using situations from outside the classroom that are of particular interest or meaning to them (Rivet & Krajcik, 2008), and also help students cross cultural borders between Western science and their own culture. In order to contextualize the 8th grade IQWST biology unit for Nahua students, the first step is to identify the culture in which students' prior knowledge is contextualized, by uncovering reasoning biases and specific knowledge that is culture-specific, and then to introduce the new cultural context of Western science. In this sense, contextualization in this study goes beyond helping students develop interconnected understandings of science concepts within the context of a relevant real-world situation guided by a driving question (Krajcik & McNeil., 2008; Rivet & Krajcik, 2008). Contextualization in this study also refers to pedagogical strategies that address culture-specific reasoning biases that support students in efforts of code-switching between cultures (Snively and Corsiglia, 2001). Such contextualization might discuss the differences between the explanation for the origin of corn provided by Nahua myths and Western science (see Methods section, p.34, for detailed example).

This perspective of contextualization, driven by the frameworks of Culturally Relevant Pedagogy and Cross-Cultural Science Education will guide the adaptation of the 8th grade IQWST unit on genetics and natural selection to Nahua students in the Mexican region of Zongolica. It is expected that after the implementation of the contextualized unit at this site, a model of Culturally Relevant Science Education can be proposed that could possibly be implemented in other contexts where minority culture students struggle to succeed at school science. Such a model would support these students to gain awareness that indigenous people can do science, that their cultural heritage is not a limitation to making great contributions to science, and that learning

Western science can be an empowerment tool that enables students to become active citizens advocating for equity in their societies.

2.2. Why Natural Selection?

Biology is the science that may offer the answer to some of the most pressing issues of the 21st century: sustainable food production, protection of the environment in the face of climate change, renewable energy, and improvement in human health (NRC, 2009). Citizens need a fundamental understanding of living systems in order to contribute to the solution of these societal issues and to understand and participate in the decision-making surrounding these issues. One fundamental tenet essential for understanding the living world is natural selection, which is the main mechanism of biological evolution. As Theodosious Dobzhansky, one of the most important scientists of the 20th century puts it: "Nothing in biology makes sense except in the light of evolution."

Natural selection was originally proposed by Charles Darwin in 1859, as an explanatory mechanism for the astonishingly diversity of life forms on Earth; this idea has become a unifying theory in biology. The centrality of evolution as one core concept in science continues to be highlighted today. For instance, Rutherford & Ahlgren (1990, p.63) in *Science for All Americans* state that: "The modern concept of evolution provides a unifying principle for understanding the history of life on earth, relationships among all living things, and the dependence of life on the physical environment." Natural selection is also highlighted by diverse organizations advocating for the improvement of science education as an idea that all students should master by grade 8. For example, the National Resources Center in its recent *Framework for K-12 Science Education* (NRC, 2012, p.140) indicates that students need to understand that "a core principle of the life sciences is that all organisms are related by evolution and that evolutionary processes have led to the tremendous diversity of the biosphere. There is diversity within species as well as between species… Evolution and its underlying genetic mechanisms of inheritance and variability are key to understanding both the unity and the diversity of life on Earth." This broad understanding is fundamental to making sense of emerging research that affect the ways we live.

Other important institutions advocating for the improvement of science education recommend that students should complete their K-12 education with a thorough understanding of natural selection. For example, the National Science Teacher's Associations (NSTA, 2003, p.1), "strongly supports the position that evolution is a major unifying concept in science and should be included in the K–12 science education frameworks and curricula." The NSTA further asserts that if students fail to grasp the concept of evolution they will not achieve the level of scientific literacy they need. Additionally, Antolin and Herbers (2001) assert that key concepts, like evolution, are essential for understanding other core ideas of science and can help build the foundation for future learning.

The fundamental need for all citizens to have an understanding of natural selection becomes even more clear when we consider the emergence of new infectious diseases, the development of antibiotic resistance in bacteria, the agricultural relationships among wild and domestic plants and animals, and the conservation of ecosystems. These are only some of the many real-life medical, agricultural, and environmental issues that influence the quality of life of people in the 21st century. Evolutionary reasoning has informed medicine in areas such as the interaction between disease organisms and host response, causes of disease resistance and virulence, and new approaches to medical care. Natural selection has contributed to explanations of crop varieties and crop improvement. Other scientific fields like environmental conservation and climate change also use the idea of evolution as an explanatory framework to advance explanations about the phenomena they study.

As Antolin and Herbers (2001) note, an understanding of evolution will help students form a knowledge foundation that can support informed decisions (political, social, or individual) regarding science and technology. This perspective can also be extended to students who live in conditions of poverty and social oppression, because this understanding will facilitate their active and informed participation in decision-making regarding aspects such as food security, health, and environmental conservation. To address the needs of historically underserved groups, this study aims to contextualize a curricular unit in the topic of inheritance and natural selection for a group who has been excluded from fruitful participation in decision-making that pertain to basic aspects of their own quality of life: the Nahuas of la Sierra de Zongolica in Mexico.

2.3. Reasoning Biases when Explaining Natural Selection

Natural selection as the mechanism for biological evolution has been documented to be one of the most difficult topics to teach and learn among other core science concepts (Beardsley, et al., 2012; Gregory, 2009). Why is natural selection so difficult to understand? Various scholars have demonstrated that certain reasoning biases such as essentialism and teleological thinking pose significant barriers to the understanding of natural selection (Kelemen, 2009, 2012; Gelman & Rhodes, 2012; Shtulman & Schulz 2008; Shtulman & Calabi, 2012), even surpassing in significance the influence of cultural aspects such as believing in a creator god (Rosengren & Evans, 2012). Taking into account these studies, this dissertation will first explore whether the Nahua students in Zongolica exhibit these reasoning biases (essentialism and teleological thinking) in order to use this information to adapt the IQWST unit to foster a better understanding of natural selection.

The first reasoning bias, essentialism, is defined in this study as Gelman (2009, p.9) has defined the construct: "a two-fold set of intuitive beliefs: that certain categories are real rather than human constructions (i.e., these categories are thought to be natural, discovered, information-rich, carving nature at its joints), and that these natural categories possess an underlying causal force (the "essence") that is responsible for category members being the way they are and sharing so many properties." Exhibiting an essentialist bias to explain the natural world, individuals see species (natural categories) as unchanging and stable, and see all the members of a species as sharing some unobservable, underlying quality (i.e., the essence) that causes its observable characteristics (Gelman & Rhodes, 2012). For example, people tend to define cats as four legged animals that purr and are covered with fur, and although this generalization is useful to make inferences about new kinds of cats we have not seen before, it also limits our realizations that there are hairless and mute cats that are, nevertheless, still cats.

Reasoning about biological species in this manner interferes with understanding natural selection because a key idea in the Darwinian theory of biological evolution is that species may change over generations (the distribution of traits within a population of the same species may change over time). In contrast to this idea, an essentialist bias may cause a student to believe that species are immutable entities and to focus on the similarity among members of the species rather than on the variation among them (Shtulman & Calabi, 2012), even when they know that the members of the species grow, change form, and transmit features from one generation to the next (Waxman, Medin, & Ross, 2007).

This essentialist bias has been observed across cultures and across ages: middle-class U.S. (Evans, 2001), India (Mahalingam, 2003), Brazil (Diesendruck, 2001; Sousa, Atran, & Medin, 2002); the Vezo in Madagascar (Astuti, Solomon, & Carey, 2004); the Yucatec Mayans of Mexico (Atran et al., 2001); the Yoruba in Nigeria (Walker, 1999); the Torguud of Mongolia (Gil-White, 2001); and the Menominee in the United States (Waxman, Medin, & Ross, 2007). This bias towards focusing on the similarity among individuals of the same species leads to a "transformational" understanding of the theory of evolution where an individual changes in response to environmental pressures, as opposed to the accurate "variational" theory of evolution where populations change over time as differential reproduction and mortality acts on the pool of genetic variability of the population (within-species variation) (Shtulman & Calabi, 2012). However prevalent this tendency of reasoning about an organism's appearance and behavior in terms of an "essence" inherited from its parents, it has not been documented for Mexican Nahuas. It may be that their beliefs and culture-specific ways of reasoning about the natural world cause them to be more or less essentialist thinkers. In either case, information about Nahua ways of reasoning is key to appropriately contextualizing the IQWST unit to the specific reasoning biases exhibited by this ethnic group.

The second reasoning bias is teleological thinking: the tendency to explain phenomena by reference to function. In the case of reasoning about the natural world, the teleological bias involves the tendency to believe that organisms possess their current traits because those traits perform functions that help survival (Kelemen, 2012). This type of reasoning focuses on function as the sole explanation for trait evolution, ignoring events such as mutation, competition, and differential reproduction rate. Therefore, students who are biased towards teleological thinking tend to explain natural selection in terms of the needs of an organism rather than as change in the frequency of traits within a population due to the comparative advantage (differential reproduction and survival) connected to certain traits in a given environment.

These teleological beliefs about natural selection have been demonstrated to be prevalent in children and adults (Kelemen & Rosset, 2009; Schtulman, 2006; Legare, et al., 2008), and according to Kelemen (2012, p.71) they are "potentially embedded in a framework of implicit underlying intentional assumptions about nature." Students come to class with cognitive tendencies and engrained misconceptions wherein purpose is attributed to living and non-living things that make it difficult for them to grasp the

Darwinian theory of evolution. For example, a student exhibiting a teleological bias might affirm that giraffes have long necks in order to eat leaves from tall trees. This explanation seems logical to the student and satisfies her need to explain the phenomenon under observation, but conflicts with the scientific explanation for the anatomical traits of giraffes (genes for elongated neck vertebrae have been passed on for multiple generations because the individuals with those genes have had an advantage in terms of survival or reproduction in the environment where they live). The latter is a causal explanation for the question, "Why do giraffes have long necks?" while the former would be a teleological explanation to the same question.

Teleological explanations are hypothesized to be offered more frequently when students lack knowledge of scientifically physical-causal explanations of natural phenomena (Kelemen, 2012). Explanations that include goal-directed natural agency are even offered by adults when their knowledge base about the biological world is not sufficient for them to build a causal-based mechanistic explanation (Kelemen & Rosset, 2009). This tendency of lay adults and children to think about the natural world in teleological terms has been demonstrated in North American samples (Kelemen, 2012, Kelemen & Rosset, 2009; Schtulman, 2006; Legare, et al., 2008) but no information is available about the teleological biases of Mexican Nahua children or adults. Certainly, Nahua students' knowledge base about plants and animals is richer than that of urban students, but we still do not know whether this rich knowledge base and other contextual factors such as the culture-based beliefs of this ethnic group limit or facilitate their overcoming of teleological explanations when learning about natural selection.

As argued, both essentialism and teleological biases underlie the development of misconceptions or naïve theories about natural selection (Rosengren & Evans, 2012). Therefore, this study does not start with a simple inventory of common misconceptions among Nahua students, but with documenting the reasoning biases that underlie those misconceptions. Contextualizing the IQWST unit using this information specific to

Nahua students will facilitate the Nahua students' learning of natural selection, because the psychological roots of their misconceptions will be uncovered and addressed. It is expected that after learning with the contextualized unit, the students will be capable of providing explanations about natural selection based on causal, mechanistic principles, which are rooted in within-species variation, thus gaining deep understanding of the way that the science of the Western culture explains biological evolution.

2.4 Quality Curricular Materials to Teach about Natural Selection: IQWST

Research on student learning indicates that even after relevant instruction, students have difficulty understanding ideas about natural selection and genetics (Samarapungavan & Wiers, 1997; Settlage, 1994; Bishop & Anderson, 1990; Sinatra, et al., 2003). The difficulties reported for middle school students in this area should not be interpreted as a lack of reasoning abilities or attributed to the topic not being developmentally appropriate for this age group, but rather as the result of inappropriate curricula and instruction (Stern, 2003; Stern & Roseman, 2004). Most textbooks and interventions focus on several concepts related to biological evolution without helping students make connections among them, or devote limited time to the concept (e.g. two to four weeks), or both (Beardsley, et al., 2012). Those approaches are ineffective, as students exhibit persistent misconceptions and reasoning biases when learning about natural selection. Therefore, curricular materials are needed that help students to develop a sophisticated and interconnected understanding of natural selection. One curricular unit that devotes time (designed for eight weeks) and emphasizes the interconnection between a few key concepts (within-species variation, inheritance, and adaptation) is "Why do organisms look the way they do?", one of the biology units of the middle school science curriculum IQWST (Investigating and Questioning our World through Science and Technology).

IQWST is a reform science curriculum developed by researchers in science education at the University of Michigan, NorthWestern University, the Weizmann Institute of Science, and Project 2061. IQWST can be considered a high-quality curriculum because of multiple features: 1) it recognizes the importance of building on students' prior knowledge by signaling common ideas students might bring to the classroom; 2) it includes relevant phenomena for making scientific ideas plausible to students; 3) it includes representations that make abstract ideas intelligible for students; 4) it provides supports for teachers to guide students' interpretation of their learning experiences; 5) it includes strategies for facilitating the transfer of knowledge; 6) it provides a purpose for every lesson; 7) it encourages and promotes students thinking; 8) it embeds assessment tools for teachers to monitor learning; and 9) it develops concepts in the context of scientific practices (Stern & Roseman, 2004). These features are based on current research and are widely accepted as indicators of high-quality curricular materials (Stern & Roseman, 2004; Roseman et al., 2010; National Research Council, 2007 and 2012).

This IQWST curricular material is an ideal choice for fostering students' learning in contexts where teachers' subject matter and pedagogical knowledge are weak, the infrastructure is poor, and/or the ideas that students bring to the science classroom might conflict with modern Western science, as is the case of indigenous schools in rural Mexico. Moreover, IQWST emphasis on core ideas in science, project-based science, and the development of scientific practices (Krajcik & Sutherland, 2009) fosters the understanding of natural selection in this national context. The few studies that have successfully fostered understanding of these concepts are similar to IQWST in their use of inquiry/project-based approaches combined with collaborative learning strategies, and scaffolded scientific explanation building (Passmore & Stewart, 2002; Sandoval & Reiser, 2004).

IQWST's project-based learning approach (PBS) motivates students to become engaged in cognitive apprenticeships where more knowledgeable others help students learn science (Collins, Brown, & Newman, 1989; Krajcik & Blumenfeld, 2006; Krajcik & Sutherland, 2009). These knowledgeable others can be peers, teachers, or members of the community, which facilitates the adaptation of IQWST units so that they are culturally relevant for indigenous schools, where community involvement in the educational process is highly valued. In the specific case of Nahua students, a PBS curriculum is especially suitable because it provides multiple opportunities for students to work cooperatively to solve a meaningful common problem, which is compatible with cultural norms of social interaction among this group and other indigenous groups (Pewewardy, 2003; Castagno & Brayboy, 2008). Additionally, because indigenous students in Mexico have unique worldviews about how the natural world works, they need to learn Western science in a relevant way, by experiencing ways that other cultures understand the world and not by memorizing facts for a test. In this sense, IQWST's focus on scientific practices is ideal. The students who learn science with IQWST experience and practice the disciplinary norms and ways of knowing employed by scientists in the Western culture as they construct, evaluate, communicate, and reason with knowledge to explain, predict, and describe phenomena (Krajcik & Sutherland, 2009).

An additional aspect of IQWST that contributes to the students' construction of a sophisticated understanding of core science ideas is its coherence. Curriculum coherence is defined as the alignment of the specified topics, the depth at which the topic is studied, and the sequencing of the topics within and across the grades (Schmidt, Wang & McKnight, 2005; Krajcik & Sutherland, 2009). More specifically, intra-unit coherence refers to "the coordination between content, scientific practices, learning goals, curricular activities, and assessments within a unit" (Krajcik & Sutherland, 2009, p.3). In the unit "Why do organisms look the way they do?", core concepts such as within-species variation, inheritance, and adaptation are aligned with scientific practices such as explanation building, and together these drive instructional activities and assessments. As a result, students achieve a sound understanding of microevolutionary principles that they then use as evidence to explain macroevolutionary processes such as plant domestication. This approach to learning natural selection has proved successful (Evans, 2008) because it is possible to observe microevolution in relatively short periods of time and it does not conflict with students' religious/cultural beliefs.

IQWST has been successful in North American classrooms (the audience for which it was designed), namely in Detroit, MI; Chicago, IL; Evanston, IL; Jacksonville, Florida; Lubbock, TX; Ann Arbor, MI; Tucson, AZ; the District of Columbia, and rural areas of Michigan (Krajcik & Sutherland, 2009). To ensure that this curricular unit is effective in a Mexican Nahua school it needs to be contextualized to the Nahua culture. In order to do so, as explained in earlier sections, the reasoning biases and prior knowledge of Nahua students will be uncovered so that they can guide what aspects should be emphasized in situations from outside the classroom that are of particular interest to Nahua students, and what pedagogical strategies should be introduced so that teachers know how to support students in efforts of code-switching between cultures (the culture of science and the Nahua culture). After this process of contextualization, it is expected that the unit "Why do organisms look the way they do?" will maintain all the IQWST features that make it high quality while remaining tailored to the Nahua context. This effort of contextualization is relevant because curricular materials have important impacts on instruction and student learning, determining to a large extent what and how subjects are taught (Stern & Roseman, 2004). Therefore, having a contextualized high quality unit on natural selection will provide opportunities for Nahua students to become biologically literate(Lopez & Hasler, 2000).

CHAPTER 3: RESEARCH DESIGN

To contextualize the 7th grade IQWST biology unit for Mexican Nahua students, the first step was to identify the culture in which students' prior knowledge was contextualized. This was achieved by exploring traditional Nahua oral narratives and practices regarding the natural world and by uncovering reasoning biases and specific culture-specific knowledge (Kelemen, 2009; Gelman & Rhodes, 2012; Shtulman & Schulz 2008). In this sense, contextualization in this study goes beyond helping students to develop interconnected understandings of science concepts within the context of a relevant real-world situation guided by a driving question (Rivet & Krajcik, 2008). Contextualization in this study also refers to introducing pedagogical strategies in the curricular materials that address culture-based practices and traditions, as well as culture-specific reasoning biases that shape students' understanding of the world, so that new curricular features can be designed to support students in efforts of border-crossing between their culture and the culture of Western science (Snively and Corsiglia, 2001).

This approach to contextualization guided the adaptation of a 7th grade biology unit on genetics and natural selection for Nahua students in the mountains of Veracruz. The analysis of the implementation of the contextualized unit led to the creation of a model of CRSE that could be implemented in other schools where minority culture students struggle to succeed at school science.

To gain a richer understanding of the Nahua students' experiences learning within a contextualized science unit, this study used a mixed methods approach. In this way, strong evidence supporting the research hypothesis being tested can be

corroborated through the convergence of reasoning tasks, phenomenological data, and test scores. This approach is widely accepted in educational research, as Johnson & Onwuegbuzie (2004) indicate: "A key feature of mixed methods research is its methodological pluralism or eclecticism, which frequently results in superior research (compared to monomethod research)." Guided by the main research question: "What does it mean to contextualize science curricula in a culturally relevant manner for indigenous middle school students so that learning of challenging concepts is facilitated?" Data was collected through three interconnected studies:
1) Teleological reasoning patterns exhibited by 7th grade students and adults in the community of San Pedro de Tequila; 2) Essentialist reasoning patterns exhibited by 7th grade students and adults in the community of San Pedro de Tequila; and 3) Experiences of students when border crossing between their own culture and the culture of Western science.

The first and second studies are quantitative in nature; the third study presents a qualitative approach. Results from the first three studies provided information to contextualize the IQWST biology unit in a culturally relevant manner for Nahua students of the community of San Pedro de Tequila, Veracruz, Mexico. The continued development of these three studies during the enactment of the unit provided the data necessary to propose a process of culturally relevant curricular contextualization including outcomes and mediating factors.

3.1. Site Selection

I have been involved for the past nine years with the Latin American Network for the Improvement of Science Education. As part of my involvement I collaborated with the Mexican National Program of Innovation in Science Education (INNOVEC) in 2008. During professional development seminars, we discussed the need for materials that are contextualized to the lives and language of Mexican students. I developed an interest not only in contextualization of science instruction and curricula but also in providing science access to ethnic minority students through contextualized curricula. I shared this interest with the board of the Mexican program who were in need of proving to the national government that indigenous schools could successfully develop the program. This justification was necessary because the development of the program in indigenous schools often demands more resources (supplying materials and professional development is more costly). Only two indigenous schools in the country participate in the program: one school had participated for a year, and the science teachers had received professional development in "hands-on" science, while the other school was about to begin participation. One program member, one government official from the Veracruz' Secretary of education, and myself visited the school to describe the research to the teachers and principal. The school's three science teachers and principal enthusiastically agreed to be part of the study (though one of these teachers later decided not to participate). The school selection was a matter of the circumstances of the National program of science education and not a preference of the researcher.

3.2. Researcher Identity and Positionality

My identity as Colombian and a researcher facilitated my initial entrance to the community of San Pedro de Tequila and to the middle school in this indigenous community. The adult members of the community and the students saw me as "güera", that is a person with lighter skin who is not a member of their community. This term is not derogatory but highlights the status of outsider to the community. This outsider status was further reinforced by my accent in Spanish that is distinctly Colombian and easily distinguishable from most Mexican accents. This "outsider" status sparked some curiosity among adults in the community who showed a willingness to converse with me. During my initial interactions with adults, they tended to assess my motivations to live in the community rather than the nearby city (50 minutes away) where most teachers live, my ways of interacting with them, and my stances towards doing research in a school of their community. This cautious behavior is rooted in the pronounced discrimination that indigenous communities face by members of the mainstream society (Gómez Lara, 2010), and are also due to negative experiences this community has had with researchers in which the Nahua have felt that their knowledge was exploited and they received no recognition.

I started to go to church and to the food market on Sundays to buy my food and socialize with people. I also walked from the house I was staying to the town's center on weekdays, so that I could interact with people and they could ask me questions about my research or myself. Multiple aspects of my life were foreign enough for them to set me apart from Mexican mestizos (e.g. choosing to work in their school, instead of being sent by the government; being unmarried and without children of my own; having lived in different countries; and living in an indigenous community by my own choosing, among others). Other aspects of my life were similar to theirs, such as the experience of migration to the United States (common among members of this community who have crossed the border and lived in the U.S. several times for extended periods) or being bilingual. These were the themes of multiple conversations with adults of the community while we ate lunch in the local "comedor", a small kitchen where one of the wise women of the community serves traditional food to locals on a daily basis. My closeness to this woman allowed me to meet other wise men and women in this community and gained me an entry point to better understanding their world, while remaining an outsider. A testimony of the rapport that I developed with the community is that I received invitations to attend private events such as first communions, birthdays, celebrations associated with "el día de muertos" that are usually attended only by family members and close friends, or just lunch with wise men of the community.

These experiences were key when I started to teach in the school, because the students had seen me before and they frequently said “ah si, yo se donde la maestra vive, yo la he visto por las tardes” (I know where the teacher lives, I have seen her in the afternoons.” “La maestra,” is the other term I was referred as, implying both my status as a teacher and having a graduate degree. In my initial interactions I insisted that they should call me Ingrid, but some people never did, and I later understood that “la maestra” denoted respect and even affection. This familiarity with students was crucial; when one of the participant teachers decided to withdraw from the study, I became the science teacher in one of the classrooms, and students felt safe talking about community practices and experiences of discrimination. Being close to the community was also crucial for motivating adult members of the community to come to the classroom for specific activities.

What I considered a successful interaction with the community of San Pedro de Tequila created tensions with the teachers in the middle school. Because I had the support of the National program of innovation in science education and the support of the State of Veracruz’ to conduct this study, some teachers felt I was somehow supervising their practices and “spying on them.” Those who felt suspicious reinforced their feelings of uneasiness when during breakfast (all teachers had breakfast together in the school’s kitchen) I restrained from laughing at sexist or racist remarks or jokes. I also expressed concern when students were left unattended for multiple class hours in a day (because a teacher would not show up or would stay at the teachers’ room). All teachers and the principal in the school also knew that I was living in the community and was close to several adults in the community, which made them suspicious that I was going to communicate irregularities to the community. Despite holding an all-school meeting to clarify the goals and methods of my research, to reassure them that I would protect their confidentiality (students and teachers’ names), and would not be involved in interactions other than academic with the Secretary of Education, some teachers decided not to cooperate with my investigation or hold conversations with me. For this reason, one of the science teachers who had originally agreed to participate withdrew from the study. In consequence, I was advised by the principal of the school and the Secretary of Education to teach the science class myself in one classroom, and so I did. In contrast, the third science (and math) teacher was a close collaborator of the study, working with us by planning lessons that would help students better understand representations of data that they needed to understand population change; the Spanish language teacher worked with us by having students review some of the reading in the students' guide in her class; and the technologies and social studies teachers were constantly inquiring about the results of the study and expressing their support. I describe these situations to illustrate how for the teachers I was also an outsider, but in contrast to my relationship with the community, this outsider status made it more difficult at times to conduct the study. Maria, one of the two science teachers for 7th grade, remained involved and engaged during the complete duration of the study.

Maria and I formed a team in which we had different areas of expertise. Maria lives in the community where the school is located, and despite not being a fluent Nahuatl speaker, she does understand the language when spoken, and takes part in traditional practices of this community. Her knowledge of the community and the Nahua culture is deep, as is her commitment to motivating students to stay in school and learn science. Maria has a bachelor's degree in chemical engineering and has been teaching in this indigenous area for ten years. She does not have formal pedagogical training and reported feeling insecure when teaching biology. Teacher 2 (myself) has a bachelor's degree in biology and graduate studies in environmental studies and science education, which allowed me to develop deep pedagogical content knowledge of biology. However, my knowledge of the Nahua culture was recent and limited; I also lacked experience as a teacher of middle school in the Mexican public system. As a team, Maria and I were a strong teaching team, and we were supportive of each other inside and outside the classroom.

The decision to become a science teacher for one of the two groups increased the fidelity to implementation of the contextualized unit, and provided an opportunity for professional development for Maria (teacher 1). We observed each others' classes, exchanged feedback, and planned together, ensuring that the design and enactment of the unit remained connected to the needs and cultural norms of the students and did not become another educational strategy that was imposed upon an indigenous school from the National government or a research university.

I present these various examples of my own positionality within my research site because they speak to my affordances and challenges as a researcher in this setting. Since I was interested in the experiences of the students when learning with the contextualized unit, it was critical that they recognized me as a teacher and felt comfortable sharing their traditional knowledge with me, which was facilitated by my relationships with the community. Having conserved my status of outsider in the community and school allowed me to observe interactions between students and teachers and between members of the community that I probably would not have seen had I been closer to the teachers or completely identified with and participated in Nahua culture. This outsider status motivated me to continue asking questions and reflecting about my observations and the data I collected in the field.

3.3. Pre Contextualization Stage

Because culturally relevant contextualization is conceptualized in this study as a process of curriculum design and instruction that accounts for 1) the ideas and experiences that students bring to the classroom, 2) the culturally-based psychological patterns of reasoning that underlie those ideas, and 3) the cultural practices, traditions, and societal structures that render those ideas meaningful for students; data was collected to inform these three dimensions and to design specific principles to adapt the IQWST biology unit to be relevant to the Nahua students. Because different types of data were collected at different stages of the study, I include a timeline and summary of data collection in table 3.1. In the following sections I will describe the methods used to collect these data.

Table 3.1. Summary of the multiple stages of data collection for the complete dissertation study

Research Question	Data Source	Purpose	Timeline
Do Nahua students exhibit teleological and essentialist reasoning patterns different from the normative views of Western science? If so, how do these reasoning patterns influence the learning of the Western science concepts of inheritance and natural selection?	Teleology interview with adults and students cohort 2011.	To uncover teleological reasoning patterns characteristic of this Nahua community. This information was used to contextualize the unit.	May 2012
	Essentialism interview with adults and students cohort 2011.	To uncover essentialist reasoning patterns characteristic of this Nahua community. This information was used to contextualize the unit.	May 2012
	PRE Teleology interview with students cohort 2012.	To assess the extent of teleological reasoning exhibited by students before the enactment of the contextualized unit.	Sept 2012
	POST Teleology interview with students cohort 2012.	To assess the effect of learning with the contextualized unit on students' teleological reasoning (after unit completion).	Nov 2012
	PRE Essentialism interview with students cohort 2012.	To assess the extent of essentialist reasoning exhibited by students before the enactment of the contextualized unit.	Sept 2012
	POST Essentialism interview with students cohort 2012.	To assess the effect of learning with the contextualized unit on students' essentialist reasoning (after unit completion).	Nov 2012
How do students cross borders between their culture and Western	In-depth interviews with wise women and men of this community.	To understand the social and cultural context of the 7th grade students living in the Nahua	May 2012

science culture when learning within a contextualized unit on inheritance and natural selection?	Focus groups with science teachers of the participant school	community where the study was conducted.	May 2012
	In-depth interview with the two 7th grade science teachers of the participant school		May 2012
	Focus groups with bilingual 7th grade students, cohort 2011		May 2012
	Focus groups with monolingual 7th grade students, cohort 2011		May 2012
	Field notes of the researcher		May 2012
	Interviews with wise men and women about the contextualized unit	To verify that the new activities introduced to the unit were responding to the needs of the community and accurately reflected their traditions.	Aug 2012
	Student interviews at 50% completion of the contextualized unit	To explore students engagement and ease at border crossing while learning with the contextualized unit.	Sept 2012
	Student interviews at after completing the contextualized unit	To understand students' overall experiences of border crossing after they completed the contextualized unit.	Nov 2012
	Field notes of the researcher and running records of classroom observations		Aug – Nov 2012
	Students' worksheets		Sept – Nov 2012

3.3.1. Study of Teleological Reasoning Patterns

3.3.1.1. Setting and Participants

A total of 40 students enrolled in an indigenous middle school volunteered to participate in this study in the school year 2011-2012. All 40 students were finishing the first year of secondary education, which corresponds to the 7th grade in the U.S. system. Also, 40 adults in the community volunteered to participate, ranging in age between 40 and 70 years.

All students were interviewed in Spanish by the author in an empty classroom of the public middle school that serves the community of San Pedro de Tequila. All adults were also interviewed in Spanish by the author. The author and one of the school's local science teachers interacted in common spaces with the adult members of the community (main square, government house, food stands, roads and trails transited by people); during those interactions the science teacher introduced the author to the adult, the study was socialized, and the adult was invited to participate. Some of the participants expressed a desire to be interviewed immediately, in which cases the adult was interviewed in a public space. Otherwise, the adult provided a convenient time to be interviewed in his/her home. All participants are fully bilingual in Spanish and Nahuatl and live in the community served by the school where this study was conducted. All interviews were audiotaped for later transcription and coding.

3.3.1.2. Data Sources and Procedure

An individual interview was designed by adapting the original task proposed by Hollander, Gelman, and Manczak (2011), aimed to uncover teleological vs. causal reasoning patterns in children and adults. In this original task one of the domains under exploration was "artifacts," but because this study is concerned with the understanding of natural kinds only, this domain was replaced by a new one: plants. Children and adults in this community are knowledgeable about local plants; this domain reveals whether or not children and adults in this community apply teleological reasoning to plants.

The interview was structured around 24 items. Items included 8 animals, 8 plants, and 8 non-living natural kinds (e.g. stars), each accompanied by a color photograph displaying the target property (see Table 1 in appendix). Half the questions within each domain concerned a static physical feature (e.g., "Why do horses have long necks?" or "Why are rocks pointy?") and half concerned an action (e.g., "Why do dandelion seeds fly with the wind?" or "Why do dogs bark?"). Static vs. action was included in the study because it has been shown that static features may be particularly susceptible to teleological explanations, and most prior studies have focused only on static features (Keil, 1994; Casler & Kelemen, 2008; Kelemen, 1999c, 2003). Also, half of the participants were randomly assigned to a generic condition, meaning that the phrasing of the question referred to all the members of a category (e.g. cats). The other half was assigned to the specific condition, meaning that the question referred to a single member of the category (e.g. that cat). The condition—generic vs. specific—was included in the design of the study because teleological responses may be offered more frequently in response to generic versus specific wording (Cimpian & Markman, 2009). A scheme of the design is shown in table 3.2.

Table 3.2. Design for teleology study

Domain	Property	Items			
Animal	Static	Dog	Frog	Opossum	Rabbit
	Action	Cat	Horse	Pigeon	Squirrel
Plant	Static	Dandelion	Mayflower	Avocado	Tomato
	Action	Corn	Oak	Leave	Cactus

Non living natural kind (NLNK)	Static	Ice	Volcano	Cloud	Stone
	Action	Gold	Mountain	Rock	Star

Participants were tested in Spanish and individually by the author whose native language is Spanish. The author provided general instructions: "I am going to show you some pictures and ask you some questions. You can tell me if you don't want to answer any more questions. Are you ready?" Once the student indicated that he or she was ready, the researcher proceeded with asking the 24 questions. For each, the author first placed a laminated photo of the target animal/plant/NLNK on the table (e.g., a cat), provided a framing statement (e.g., "I'm going to ask you a question about that cat" [specific] or "I'm going to ask you a question about cats" [generic condition]), followed by the question itself (e.g., "Why does that cat have a tail?" [specific] or "Why do cats have tails?" [generic]). No feedback was provided, aside from simple non-directive responses (e.g., "OK", "good"). Participants were randomly assigned to either the non-generic or the generic condition. The order of items within a block was randomly determined, separately for each participant, by shuffling the cards at the end of each interview. Responses were audio recorded and later transcribed and coded.

3.3.1.3. Data Analysis

Responses were coded as teleological, causal, or non-explanatory, according to the following coding scheme.

Table 3.3. Coding scheme to explore teleological reasoning patterns

Code definition/example
- **Teleological responses:** The tendency to explain behavioral and anatomical features of animals, physiological processes of animals and plants, and characteristics of non-living natural kinds by reference to a purpose or a consequence (Kelemen & Rosset, 2009). In the following examples, a "why" question was asked; however, the subject answered as if

the question was a "what for" question. Notice that the first question asks about the reason pigeons have wings and the subject provides a reason linked to the purpose of the wings but not what caused the pigeon to have wings (e.g. "because pigeons inherit that from their parents" as opposed to teleological answers such as "to be able to fly" or "so they can look for food".) In the second example, a question is asked regarding the reason for the scaly nature of oak's bark, and instead of providing a reason for oaks to have scaly bark (causal reasoning), the student provides an answer focused on the purpose such a bark serves to the tree (teleological reasoning).

Example:
I: Why do pigeons have wings?
S: To be able to fly.

I: Why do oaks have scaly bark?
S: To get protection from the cold weather.

All the responses coded teleological were classified in two subcategories: "self" and "other", because research has demonstrated that not all the kinds of functions invoked by children and adults are the same. Some functions can reference self-serving ends relevant to the survival of an organism, while other functions reference other-serving functions more typical of artifacts (Casler & Kelemen, 2008). (e.g., a long neck in a horse can be considered as existing for an animal's self-serving need such as obtaining food, while people referencing an other-serving function may maintain that the horse's neck exists so a rider can hold to the horse for avoiding falling.)

Example:
I: why do oaks have scaly bark?
S: to protect themselves from and avoid water to get inside them

I: Why do oaks have scaly bark?
S: because we use it to burn something, as firewood.

All the explanations coded as teleological were further coded according to two categories:

- **Self:** responses where an animal or plants' property is described as serving a goal or purpose for the bearer of the property.

Example:
I: Why do dogs bark?
S: To get food from people.

- **Other:** responses where there is reference to a function that is of service to other living thing or person.

Example:
I: Why do dogs bark?
S: To alert people of danger.

- **Causal responses:** The tendency to explain behavioral and anatomical features of animals, physiological processes of animals and plants, and characteristics of non-living natural kinds by reference to a prior process or event that gave rise to a feature of the animal/plant/non living thing. It involves a pre-existing or causal antecedent, state, or mechanism, without which, the activity in question would be less likely to occur. Causal explanations do *not* refer to any future outcome. This code includes two sub-codes:

- Causal – Western Science Knowledge (WSK):

References a biological or physical mechanism that is accurate according to modern Western science knowledge. In the following examples students make reference to the mechanism of inheritance or information coded in the DNA as a cause for the existence of a certain feature in an organism.

Examples:
I: Why do cats have tails?
S: Because that is the way they inherit it from their parents.
S: Because… they have their DNA that way… DNA for having spines.

- Causal – Traditional Indigenous Knowledge (TIK):

Reference to a prior cause that is mentioned in traditional Nahua stories, or cultural practices of this community. In the following example, the student makes reference to a traditional practice of fruit handling in this community as the cause for avocado ripening.

Example:
I: Why do avocadoes get ripe?
S: Because after they are cut when green if they are put on the heat, I mean, they are put inside and wrapped in a newspaper, they start getting ripe little by little.

- Causal – Other:
  - References to pre-existing mental states, desires, and preferences.
  - Obligation or permission—someone told them to do X or allowed them to do X, either directly or indirectly.
  - Also includes responses that refer to a mental state + restatement/rephrasing of activity in question (merely refers to intentional cause and not to a goal beyond the activity itself.)

In the following examples, participants include in their answers a pre-existing feeling (feeling threatened), or a pre-existent desire (wanting sunlight), or a pre-existing preference (liking flies is a precondition to eating them).

Examples:

I: Why do opossums climb trees?
S: They feel threatened.

I: Why do tomato plants move their leaves towards the sun?
S: Because they want sunlight.

I: Why do toads catch flies?
S: Because they like it.

Also, in this category are the responses in which the speaker does not make any reference to either WSK or TIK, or mental states. Only a prior event that gave origin to the trait or behavior addressed in the question. For example, in the following response the presence of thieves is a prior event that caused the dog to bark, but the presence of thieves is not a psychological cause (mental/inner states of the dog) or a cause that is typically found in Nahua traditional narratives.

I: Why do dogs bark?
S: Because there is people nearby. Because there are thieves nearby.

Non Explanatory Responses:

- Do not state a reason, cause, or purpose.
  - Includes mention of pre-existing, but non-causal state. E.g., if they imply that "that is just the way it is."
- Near-verbatim repetitions of the question.
- Merely describing how, when, or where the activity takes place (without also mentioning any intentional cause or a consequence).

Examples

- Because it is.
- Because those are their wings.
- I do not know.

By the end of the coding process, there were three groups of responses: teleological, causal, and non-explanatory. To explore the effects of domains (animals, plants, or NLNK), property (action and static), and condition (generic and specific) on students' responses, a repeated-measures ANOVA was performed separately for each response groups.

3.3.2. Study of Essentialist Reasoning Patterns

3.3.2.1. Setting and Participants

The participants were the same as in study 1: 40 students and 40 adults (see section 3.3.1.1). After completing the interview of study 1, participants were given a five minutes break and asked to continue with "the second part of the interview," which focused on essentialism described below. The teleology and essentialism interview were conducted in the same session responds because it is difficult to access the homes of some community members, and in order to minimize class disruption for the students. It was easier for participants to commit to a one-time session of 15 to 25 minutes, as opposed to two sessions at different times.

3.3.2.2. Data Sources and Procedure

An individual interview was designed by adapting the original task proposed by Shtulman and Schulz (2008) to uncover essentialist reasoning patterns about animals in children and adults. The interview was modified from the original by replacing three insects with three plants. This modification was made because the present dissertation focuses on how students can better learn the concept of natural selection; therefore, it is important to have information about whether students reject the idea of within-species variation both for animals and plants. One additional modification was to include only organisms with which the Nahua students are familiar, thus ensuring that they have domain-specific knowledge regarding the causal bases for these animals' features, and will thus provide rich explanations for such items.

The interview was designed to assess the variability of one behavioral property (e.g. nesting in trees), one external anatomical property (e.g. having wings), and one internal anatomical property of three different animals (e.g. having sturdy skeletons), as well as one external anatomical property, and one internal anatomical property for three different plants (see Table 3.4). The order of presentation for the types of properties was randomized across animals and plants, and the order of presentation for animals vs. plants was randomized across participants.

Table 3.4. Animals and plants and their properties, organized by property type

Organism	**Property type**	**Description**	**Function**
Squirrels	Behavioral	Build nests in trees	To get shelter
	External	Have long puffy tails	To help them jump between trees
	Internal	Have big muscles in their hind legs	For climbing and running
Hens	Behavioral	Preen their wings and body	To remove parasites
	External	Have feathers	To stay warm
	Internal	Have a large reproductive system	To develop the eggs
Pigs	Behavioral	Live in groups	To defend themselves from predators
	External	Have snouts	To smell and find food
	Internal	Have sturdy skeletons	To support their great weight
Pines	External	Have a large root system	To get as much water as possible
	Internal	Have sap inside the trunk	To transport nutrients
Chili peppers	External	Have lots of leaves	To get as much sunlight as possible
	Internal	Chili peppers contain a chemical that makes them spicy	To avoid being eaten by mammals
Pumpkins	External	Have edible seeds	For animals to disperse their seeds
	Internal	Pumpkins have a chemical called ethylene inside	For the fruit to get ripe

The task was administered in Spanish by the female researcher whose native language is Spanish, as an interview structured around a laminated photo of the target animal/plant on the table (e.g., a pig), providing a framing statement (e.g., "I'm going to ask you a question about a pig") followed by a question about a property of the animal/plant. Properties were presented in the form of a generic question (e.g., "Did you know that pigs have sturdy skeletons?"), followed by a description of the property's primary function (e.g., "The sturdy skeletons help them to support their great weight"). This interview included function information because children tend to believe that only functional properties are heritable (Springer & Keil, 1989; Shtulman & Schulz, 2008).

Participants were asked one to three questions for each property, depending on their answer to each question. The first question explored judgments of actual variability (e.g., "Do all pigs have sturdy skeletons or do just most pigs have them?"). Participant who did not acknowledge variability in the feature under question were asked a second questions to explore their judgments of potential variability (e.g., "Would it be possible for a pig to be born with a different type of skeleton?"). Participants who did not acknowledge potential variability in the feature under question were asked a third and final question, requesting a reason why potential variability in that trait was not plausible for her/him (e.g., "Why couldn't a pig be born with a different type of skeleton?").

3.3.2.3. Data Analysis

Responses were coded in three stages: 1) assessment of actual variability; 2) assessment of potential variability; and 3) justification type, according to the following coding scheme.

Table 3.5. Coding scheme for essentialism study

Stage of Interview	**Code definition/example**
1. Assessment of Actual Variability	**- Code 1:** participant claimed the trait is NOT common to all members of the species. Requires no further coding. Example: I: Do you think that all squirrels build their nests in trees or just most squirrels do so? S: Only most squirrels because some of them are in different places and perhaps they do not have a place to build their nests and they build them elsewhere. - **Code 0:** participant claimed that the trait was common to all members of the species. Responses coded 0 will be further coded in stage 2 (assessment of potential variability) Example: I: Do you think that all squirrels build their nests in trees or just most squirrels do so? S: All squirrels build their houses in the trees so no one can reach them.
2. Assessment of Potential Variability	- **Code 1:** participant claimed that the trait could vary in a new member of the species. Requires no further coding. Example: I: Could a squirrel be born that builds a different type of nest? S: Yes, perhaps in the base of the tree's trunk. - **Code 0:** participant claimed that the trait could NOT vary in a new member of the species. Responses coded 0 will be further coded in stage 3 (justification type). Example: I: Could a squirrel be born that builds a different type of nest? S: No, because squirrels look for shelter to be warm and place their nuts.
3. Justification type	When an answer is coded 0 for potential variability, the student was asked for justification. Justifications can be coded in three different categories: - **Species-based justification:** participant claimed uniformity of species

	members within or across generations. Example: I: could a pumpkin be born with a different type of seed? S: I would say no I: why would you say no? S: because it would have to be a different type of pumpkin. - **Property-based justification:** participant claimed undesirability or implausibility of changing a particular property. Example: I: Could a pig be born with a different type of skeleton? S: No. I: Why not? S: Because they could not support their own weight, they grow a lot. - **Uninformative justification:** participant remained silent, stated that she does not know, or does not answer the asked question. Example: I: Could a pig be born with a different type of snout? S: Perhaps, well… I don’t know… I believe not. I: Why not? S: Because… I don´t know, well I believe (giggles) that a different snout like… I don´t know.

To explore the effects of organism type (animals or plants), and property (behavioral, internal, external) on students’ explanations of variability of traits, a two way ANOVA was performed.

3.3.3. Study of the Social and Cultural Context of the Community of San Pedro de Tequila, Veracruz

3.3.3.1. Setting and Participants

A total of nine adults and twelve 7th grade students (school year 2011-2012) participated in this study. Five adults considered by the community as wise men and women participated in an individual in-depth interview exploring their culture-based beliefs of nature and their points of view about science education provided in public schools. These wise men and women were identified by reports of the current and former principals of the local middle school, both born and raised in this community although presently living in nearby urban centers, one of the science teachers who is a member of the community. All five of them recognized the other four as wise men and women in individual conversations with the author. The four science teachers of the local middle school participated in a focus group exploring their perceptions about teaching science to indigenous students, characteristics of curricular materials they use, and students' engagement and achievement in science. Among the twelve students, six were monolingual in Spanish and six were bilingual in Spanish and Nahuatl. Each group of students participated in a focus group aimed to explore their culture-based beliefs of nature and their experiences learning science at school. The two science teachers teaching 7th grade selected these twelve students among those students who volunteered to participate, making sure that for each of the groups (monolingual and bilingual), two students were high achieving in science, two were average, and two were struggling in the subject.

3.3.3.2. Data Sources and Methods of Analysis

The theoretical frame for this study assumes that the ways in which students understand the natural world are socially situated and mediated (Moje, et. al., 2008); therefore, this study reflects a sociocultural orientation to understanding the social and cultural practices and narratives associated with natural kinds in this community; this study also draws from the cultural studies perspective, in which an emphasis is placed on understanding how everyday practices both shape and reflect broader social practices (Moje, et. al., 2000). In-depth interviewing, focus groups and ethnographic observation were applied to document the context of the community, because those are appropriate techniques for collecting data on the larger structural and discursive contexts in which the students of this community live and participate. Specifically, data was collected ethnographically by conducting individual in-depth interviews with leaders of the community (wise women and men), focus groups with students and science teachers of the local middle school, and by recording field notes and analytical memos derived from observation and participation on the everyday, in-school and out-of-school practices of the students and their families (festivities, mass, science classes, school's recess, outings to the market, etc.) during a month living in this community. This approach allowed for the documentation of the practices and narratives of this community that may influence students' foundational understandings of the natural world, as well as their preferences and expectations regarding social interactions that lead to learning and cognitive engagement.

3.3.3.2.1. In-Depth Interviews with Wise Women and Men of the Community

To gain a better understanding of this community's traditional knowledge about nature, and their perceptions about school science, an in-depth interview was conducted with five members of the community who are considered wise men/women. The title "wise men/women" is given by the members of the community to those individuals who demonstrate deep knowledge about the Nahua traditions (e.g. language, healing, arts and crafts, history), and share that knowledge in service of the community. Once these five individuals were identified (as described in section 3.1.3.1) they were approached by the author to socialize the present study and request their involvement. Once they accepted, the wise men/women were asked whether they would like to read the original version of the IQWST unit translated into Spanish, and offer comments about how the content and practices in the unit would be compatible or in conflict with the Nahua culture.

The in-depth interview was appropriate to gather this type of data because it provides a safe, comfortable setting where participants could engage in dialogue that explored sensitive issues such as their honest opinions about the IQWST unit, and the intended science unit adaptations (Brotman, et al, 2010). These five in-depth interviews constituted core information for the contextualization of the IQWST unit, ensuring that the adaptation is a collaborative effort emerging from the indigenous communities' educational needs and views. The interviews were structured around key open-ended questions, but were also conversational, with questions flowing from previous responses when possible. Because the focus was placed on seeking understanding of the participant's views, unplanned follow-up questions were asked as part of the conversation. Each interview was about one hour in duration. The key questions guiding the interviews are presented below.

Questions about animals/plants

- Are animals/plants important to your community? In your culture?
- Is someone in your community more knowledgeable about animals/plants? Why is that person so knowledgeable?
    - How did that person come to know that much about animals/plants?
    - Does this person teach what he/she knows to other members of the community? To which members? Why? How?
- Are some animals/plants more important than others in your community? Why is this so?
- How do people of the community interact with animals/plants?
- How did your children learn about these aspects of animals/plants that you just mentioned?
    - When did they start learning this?
    - Who did they learn this from?
    - Do girls and boys learn the same things about animals/plants?
    - Why is it important for children and youth to learn this?

Questions about Non Living Natural Kinds (NLNK)

- Are mountains/stars/rivers important to your community? In your culture?
- Are some mountains/stars/rivers more important than others in your community? Why is this so?

- How do people of the community interact with mountains/stars/rivers?
- How did your children learn about these aspects of mountains/stars/rivers that you just mentioned?
    - When did they start learning this?
    - Who did they learn this from?
    - Do girls and boys learn the same things about mountains/stars/rivers?
    - Why is it important for children and youth to learn this?

Questions about school science

- We have talked about animals, plants, mountains, rivers, and stars. Do children and youth in the community learn about all this at school?
- How is what they learn at school similar or different from what you just taught me about animals, plants, mountains, rivers, and stars?
- Do you think that the youth of the community should learn science at school? Why/why not?
- Is it common for people in the community to choose careers related to science or technology? For example, medical doctors, nurses, engineers, agronomists, etc. Why do you think this is?

Questions about the IQWST unit

- Have you seen the textbooks that children/youth use at school to learn science?
    - How did you have access to these textbooks? (if no access) Why is that?
- How is this unit similar or different to those textbooks?

A week after the first session the wise woman/man was contacted to record her/his feedback about the unit.

- You had the opportunity to review/read this science unit for the past week; how do you like it?
- Do you see any content/practices that could especially help students learn science?
- Do you see any content/practices that could hinder students' learning of science?
    - If you could make any improvements, what would they be?
- What changes would you introduce to the unit so it helps students to also learn all the aspects you taught me last time about animals and plants?

3.3.3.2.2. Focus Groups with Science Teachers of the Local Middle School

Two focus groups were conducted with the science teachers of the local middle school. The first one focused on understanding science teachers' perceptions about teaching science to Nahua indigenous students, curricular materials available to teach science in this context, and students' engagement in science classes. Also, there was space during the focus groups to understand these teachers' trajectories to becoming science teachers (education and experiences). These four teachers have different content expertise: two teach physics and the other two teach chemistry and biology. The chemistry and biology teachers agreed to participate in the enactment of the contextualized IQWST unit. A second focus group was conducted with these two teachers to discuss their considerations and concerns about teaching this IQWST unit, as well as to document all possible recommendations they had to contextualize this material for their students. Similarly to the in-depth interviews, the focus groups were structured around key open-ended questions, but were also conversational, including unplanned follow up questions to gain a better understanding of the teachers' views and experiences. Each focus group lasted about one hour and a half. The key questions guiding the focus groups are presented below.

Focus group 1 (four teachers)

- Tell us about your preparation to becoming a science teacher.
- How many years have you been teaching science? Where?
- What opportunities for professional development are available to you? Are those tailored to your work with Nahua students?
- Do you see students' Nahua beliefs as an advantage or an obstacle when learning science?
    - (If an advantage) How is this an advantage? How do you use these beliefs in your instruction when teaching science?
    - (If an obstacle) How is it an obstacle? What do you do to overcome the difficulties derived from student's beliefs when teaching science?
    - How would you assess the overall performance of your students in science? Why do you think this?

- Do you think that it is important for indigenous students to learn science? Why?
- Do you think your students are engaged in learning science here at school?
- What ways do you think they would become even more engaged in learning science?

Focus group 2 (two teachers)

- In the past, when you have taught inheritance and natural selection to Nahua students, what were the main difficulties students faced?
    - In your opinion, what might be the origin of these difficulties?
    - How have you addressed these difficulties?
    - What are the main strengths of the materials you currently use to teach natural selection? What are its main weaknesses?
    - You had the opportunity to review/read this science unit for the past week; how do you like it? (IQWST unit translated into Spanish with no adaptations)
    - Do you see any content/practices that could especially help students learn science?
    - Do you see any content/practices that could hinder students' learning of science?
    - If you could make any improvements, what would they be?

3.3.3.2.3. Focus Groups with 7th Grade Students

Two focus groups were conducted with the 7th grade students at the local middle school. The purpose of these focus groups was to explore the 7th grade students' knowledge about practices and narrative characteristics of the Nahua culture, and to determine the presence of Nahua culture in the students' everyday lives. These focus groups were explored students' experiences learning science in middle school. Because most, but not all, students in this school are fully bilingual in Spanish and Nahuatl, it was of interest to explore whether those students monolingual in Spanish had a different understanding of their traditions or whether they reported different experiences learning science at school. Therefore, the same key questions were used to structure a conversation separately with two groups of students, bilingual and monolingual. The key questions guiding the focus groups are presented below.

Questions about animals/plants

- Are animals/plants important to your community? In your culture?
- Is someone in your community more knowledgeable about animals/plants? Why is that person so knowledgeable?
    - How did that person come to know that much about animals/plants?
    - Does this person teach what he/she knows to other members of the community? To which members? Why? How?
- Are some animals/plants more important than others in your community? Why is this so?
- How do people of the community interact with animals/plants?
- How did you learn about these aspects of animals/plants that you just mentioned?
    - When did you start learning this?
    - Who did you learn this from?
    - Do girls and boys learn the same things about animals/plants?
    - Is it important for you to learn this? How so?

Questions about Non Living Natural Kinds (NLNK)

- Are mountains/stars/rivers important to your community? In your culture?
- Are some mountains/stars/rivers more important than others in your community? Why is this so?
- How do people of the community interact with mountains/stars/rivers?
- How did you learn about these aspects of mountains/stars/rivers that you just mentioned?
    - When did you start learning this?
    - Who did you learn this from?
    - Do girls and boys learn the same things about animals/plants?
    - Is it important for you to learn this? How so?

Questions about school science

- We have talked about animals, plants, mountains, rivers, and stars. Do you learn about all this at school?

- How is what you learn at school similar or different from what you just taught me about animals, plants, mountains, rivers, and stars?
- Does it happen that what you learn at school contradicts what you taught me today about animals, plants, stars, mountains, and rivers? What do you think/feel when that happens? How do you resolve that contradiction?
- Do you think that you should learn science at school? Why/why not?
- Do you like the science class? Why/why not?
    - What do you think would make you like science class better?
- How good are your grades in science? Why do you think that is?
    - What do you think would help you obtain better grades?
- Is it common for people in the community to choose careers related to science or technology? For example, medical doctors, nurses, engineers, agronomists, etc. Why do you think that is?

All these sources of information (transcripts from interviews and focus groups, observation records and analytic memos) were integrated using the software NVivo 10 and analyzed using five broad codes:

1. Ways of explanation of natural phenomena that are unique to the Nahua culture
2. Ways in which the Nahua culture explains natural phenomena that are similar to the culture of Western science;
3. Culture-based narratives involving animals and plants that explain aspects of life to which Nahua people have traditionally granted importance (e.g., the cultivation of corn);
4. Ways of interaction that are conducive to learning in the context of the Nahua culture; and
5. Experiences and perceptions of the community about the science education that is provided in public schools.

The following chapter presents patterns regarding essentialist and teleological reasoning as well as the culture-based practices and narratives that informed the design of new contextualized features that were included in the IQWST biology unit.

Table 3.6. Summary of sources of information used to design the contextualization features to the IQWST unit

Data source	Type of Data
• Interview about teleological reasoning patterns • Interview about essentialist reasoning patterns	Quantitative
• Interviews and focus groups • Records and analytical memos from ethnographic observation • Published ethnographies about the Nahua people of Veracruz	Qualitative

3.4. Analysis of Students' Experiences While Learning with the Contextualized Unit

Sections 3.1 to 3.3 describe data collection and data analyses that occurred prior to the contextualization of the unit, precisely because they served as the substrates for the contextualization process. The information collected in that stage (sections 3.1 to 3.3) was used to design a set of principles aligned with the Nahua culture that would make the learning of inheritance and natural selection concepts relevant for this population of students. From this point forward I will describe the stage 2 of the present study. During stage 2 two teachers enacted the contextualized unit, each one with a different group of students during the school year 2012–2013. Teacher 1 (Maria) is one of the science teachers of the indigenous school and is the only teacher of this school who lives in the community. Teacher 2 is the author of this investigation, who received authorization from the Secretary of Education and the school's principal to teach this unit to one 7th grade class. In order to better understand how the new features favored students' learning of these concepts as well as the students' ability to border cross between the two cultures (Nahua and WSK), data was collected during the enactment of the unit from the following sources:

a) Pre-Unit Enactment

- Teleology interview

- Essentialism interview
- Pre-test centered around conceptual knowledge of inheritance, population change, and natural selection
- One focus group with students

b) Unit Enactment

- Running records derived from ethnographic observations of all the classes taught by Teacher 1. These observations and running records were produced by Teacher 2.
- Field notes, reflections, and memos written by Teacher 2 after her classes.
- Semi-structured individual interviews with 25 students in week 5 (mid-point interviews)
- Student notebooks (n = 24)

c) Post-Unit Enactment

- Teleology interview
- Essentialism interview
- Post-test centered around conceptual knowledge of inheritance, population change, and natural selection
- Semi-structured individual interviews with 27 students in week 12 (after completing the unit) about their experience learning science with this unit

I did not use all of the students' notebooks (student guides) in this analysis because not all of the students were willing to give their student guides away. I explained to them how important the study was for helping other children like them to learn science, as well as how much other people would learn from the ideas that they wrote in their notebooks. After this conversation, 24 students volunteered to donate their notebooks. Among these 24 students, there were some who struggled to understand and complete activities during the enactment of the unit, students who understood and completed activities without showing noticeable enthusiasm, and students who were highly engaged and took on leadership roles in their teams. For these reasons, this sample of notebooks is representative of the two classrooms and allowed me to not to press more students to give me their notebooks for the analysis.

3.4.1. Pre- and Post-Teleology Interviews

Based on the results of the teleology interview with students from the cohort 2011–2012, this interview was refined and streamlined by excluding from its design those domains and conditions which were not statistically significant. Therefore, the domain Non-Living Natural Kinds was excluded as well as the condition Generic vs. Specific Phrasing. The final interview included sixteen items in the domain of animals and plants, half of these items portraying action features (e.g., running) and the other half portraying static features (e.g., having wings).

The pre-interview was applied to 39 seventh-grade students at the beginning of the school year 2012–2013. Because the 7th grade is the first year in the "escuela secundaria" or middle school in Mexico, the teachers did not have information regarding their students' prior academic performance that could serve to support stratified sampling based on academic performance. Therefore, half of the students of each of the three 7th grade groups were invited to participate in this interview. The 13 students from each classroom were selected randomly using a random numbers table on the class roster. This decision was made with the aim of minimizing disruptions for teachers and students, since the interviews were to be conducted during the school day. By using this system, only three students were taken away from each classroom over a single day, and most teachers experienced only a single request per day for a student to leave class in order to participate in the interview.

The post-interview was applied after the enactment of the contextualized unit, three months after the beginning of the school year. Due to attrition, only 32 students out of the original 39 participated in the post-interview.

The interviews were conducted, coded, and analyzed as described in sections 3.3.1.2. and 3.3.1.3.

3.4.2. Pre- and Post-Essentialism Interviews

Based on the results of the essentialism interview with students from the cohort 2011–2012, this interview was refined and streamlined by modifying the phrasing of questions that were confusing for students or that compromised the validity of the items (i.e., were not conducive to assessing the construct of variation within a population). Two questions were modified by adding a qualifier to a trait; that is, instead of asking whether all pigs have a snout, it was asked whether all pigs have a "rounded" snout, and instead of asking whether all hens have feathers, it was asked whether all hens have feathers "all over their bodies." The overall design of the task remained as described in section 3.3.2.1.

The post-interview was applied after the enactment of the contextualized unit, three months after the beginning of the school year. Due to attrition, only 32 students out of the original 39 participated in this interview.

The interviews were conducted, coded, and analyzed as described in sections 3.3.2.2. and 3.3.2.3.

3.4.3. Ethnographic Analysis of Students' Notebooks, Running Records, Field Notes, and Interviews with Students

This analysis is aimed at understanding both the different subjective experiences that indigenous students may have when learning school science and the instructional practices and curriculum-contextualizing features that ease the crossing of cultural borders that indigenous students must do when learning science. The data corpus that served as the basis for this analysis was composed of interviews, students' notebooks, and field notes and memos produced by the researcher. The goals and procedures for collecting these sources of data as well as their analysis are described in the following sections.

3.4.3.1. Running records and memos from classroom observations during the enactment of the biology unit

Two 7th grade classrooms were studied ethnographically, with the initial conceptual model of border crossing (Table 3.5) guiding the observation. Observations were focused on the students' experiences of border crossing between their culture and Western science culture when learning about natural selection. By observing these two classrooms on a daily basis over 12 weeks, it was possible to document the impact of the contextualization principles included in the unit on the students' crossing of cultural borders when learning science. All classes taught by Teacher 1 were observed by Teacher 2 (the researcher), who produced running records with a focus on the border crossing experience. These running records consisted of handwritten accounts of the events that occurred during each class. The researcher had a seat in the back of the classroom to minimize any distraction that she might present to students. However, because students were informed that Teachers 1 and 2 were a team and that we were conducting a study, they understood the nature of the note-taking and were comfortable when Teacher 2 shadowed Teacher 1 during group discussions or when she approached them during student-student discussion in the process of taking notes. These notes and overall running records include information about dialogues and interactions that occurred in the classroom. Furthermore, because my role as a teacher did not allow me to produce running records of my own classes, I wrote reflective notes and memos about events in my class in the afternoons following the school day.

3.4.3.3. Production of lesson plans

Because the two teachers observed each other's classes, we had a shared understanding of the process of the enactment of the unit as well as an understanding of students' learning needs. This allowed us to plan the lessons together. We used the contextualized unit as the main resource for building lesson plans, which were constructed jointly during 1.5-hour meetings once per week. During these meetings, we also exchanged feedback about teaching strategies. I was able support the teacher to develop her pedagogical content knowledge (Shulman, 1986) while she was able to support me in my effort to gain a better understanding of the Nahua culture and the context of the school. In this way we ensured that a high fidelity of enactment of the unit while at the same time refining and operationalizing strategies and activities proposed in the IQWST unit so that they would be better aligned with the culture, strengths, and needs of these particular students.

3.4.3.4. Interviews with Students

To understand the experience of the students while learning with the contextualized unit, midpoint and final post-enactment, semi-structured interviews were conducted. The interviews were conducted in an empty classroom and were audio recorded and later transcribed for analysis. The same twenty students were interviewed during the midpoint and final interviews. Each teacher asked her or his students to volunteer to be interviewed during the recess and to sign up on a list until we had 10 students from each classroom, which is about half of all of the students learning with the unit.

The midpoint interviews were conducted by a young woman and a young man who were members of the community and attending an indigenous college in the area. This decision was made in order to ensure that students felt free and safe to talk about their opinions and experiences regarding the science class. The final interviews were conducted by myself after students received their grades for that first term and knew that I was leaving to continue my studies and would cease to be their science teacher.

Although it would have been ideal to have had collaborators from the community to conduct these interviews, at this point the college students who helped with the midpoint interviews were in the field collecting data and I was unable to obtain additional help. This is one of the limitations of the final interviews as a data source. Because students had developed a bond with me as a teacher, it is likely that they opted not to share their criticisms. The questions that guided the midpoint and final interviews are presented below.

Midpoint interview, generative questions:

- Where do you live? What do your parents do for a living?
- Which is your favorite class? Why?
- How is this science class similar to or different from other classes?
- What is your favorite thing about this science class? Why?
- What is your least favorite thing about this science class? Why?
- What are the easiest and hardest things in this science class? Why?
- Do you share what you learn in the science class outside of the school? With whom do you share this?

Final interview, generative questions:

- Do you think of yourself as indigenous? Why?
- Do you think that is possible for you to use the knowledge that is characteristic of your culture in the science class? Tell me more about how and when you use it.
- How does it make you feel when you can use that knowledge in the science class?
- What do you think science is?
- Do you think it is worth learning science? How are you planning to use that knowledge?
- What do you want to be when you grow up?
- Have you ever considered being a scientist? How would you like that?
- What would you add or change to the science class so that you like it more and you are always happy during science classes?
- What makes you feel best during science classes?

3.4.3.5. Students' Notebooks

All students in the two classrooms received a notebook or student guide that contained readings, activities, worksheets, and assessments. All students registered their own evolving knowledge in a section that was purposed for this goal in the notebook.

During all classes students interacted with their notebooks and used it to write down their main conclusions from the class. Students were asked to always leave their notebooks in the classroom so that they would not be lost, except for the times in which homework was assigned that involved interactions with parents and neighbors. Only 24 students volunteered to donate their notebooks by the end of the unit enactment. Those 24 notebooks are the main source of student artifacts in the analysis. These notebooks provide evidence regarding how students made sense of the content that they were learning as well as how certain objects or activities within the unit did or did not facilitate border crossing. Thirty-five worksheets in the notebooks were considered critical events for border crossing; therefore, those 35 worksheets were selected from each one of the 24 students' notebooks (for a total of 840), scanned, and incorporated into the corpus of data in order to be coded and analyzed.

3.4.3.7. Coding and Data Analysis

All of the above-mentioned sources of data were integrated chronologically using the softare NVivo 10. All data was analyzed in its original language (Spanish) by the researcher, whose native language is Spanish. The focus of analysis was the observation of the different experiences that students had when comparing natural phenomena from the point of views of their own culture and that of Western science culture and when deciding how and when to use these two types of knowledge, as well as to develop an understanding of when learning opportunities emerged or were denied when the contextualized unit was enacted in the classroom.

With the goal of systematicity, critical events from throughout the corpus of data were selected in which students were engaged in border crossing between the Nahua culture and Western science culture. Critical events as defined by Powell, Francisco, & Maher (2003, p. 416) are "connected sequences of utterances and actions that, within the context of our *a priori* or *a posteriori* research questions, require explanation by us, by the learners, or by both." Within the framework of this study, events were considered critical in relationship to the research question: "What does it mean to contextualize science curricula in a culturally relevant manner for indigenous middle school students so that learning of challenging concepts is facilitated?" Because one of the main hypotheses of this study is that the new curricular features would better facilitate border crossing between the Nahua culture and Western science culture, events that were selected as critical either confirm or disaffirm this hypothesis.

The identification of these critical events was guided by four broad categories: 1) explicit comparisons between Nahua culture and Western science culture as a mechanism for border crossing; 2) the students' use of Nahua knowledge in science class; 3) the students' use of Western science knowledge in order to make sense of social issues affecting their lives; and 4) difficulties in border crossing between cultures. (See Table 3.5 for full operationalization and examples of each category.)

These four categories constituted the initial conceptual model of border crossing between the Nahua culture and Western science culture and guided the identification of critical events. By connecting all of the events that were representative of those categories, a narrative of the border crossing experiences of students in the science classroom could emerge and be analyzed through an ethnographic lens. I then moved away from this deductive stage in order to engage in an inductive ethnographic stage of reading and re-reading through the artifacts, interviews, and field note excerpts in each category. This allowed me to group them in smaller thematic categories by comparing and contrasting and looking for co-occurrences, absences, and linkages between events (Glaser and Strauss, 1967; Strauss and Corbin, 1998; LeCompte and Schensul, 2010), all of which would allow for a richer understanding of the students' experience of border crossing.

Table 3.7: Initial conceptual model that oriented the design of contextualization features for the science unit and the selection of data to be analyzed within the complete data corpus

Category definition / example
Category 1: **Including explicit comparisons between Nahua culture and Western science as a mechanism for border crossing** Western science content or practices that when learned favor discussion or reflection about the differences between Western science and Nahua culture, making it possible for students in this traditional setting (i.e., an indigenous school) to have easier access to science through overt comparisons of their world view with that of Western science. Boundary crossing is defined here as transition and interaction between indigenous cultural explanations of natural phenomena and the ones offered by Western science. Rationale for this example: The dialogue below is an overt, teacher-moderated discussion concerning how what a healer told them is similar to or different from a reading about athletic performance that was included in the IQWST unit. Because healing is a central theme in the Nahua culture and is present in the day-to-day life of every member of the Nahua community, children and youth learn that healing is a gift that runs in some families (i.e., that it is inherited). This explanation contrasts with the explanation of Western science that some skills and behaviors are learned and are not coded in our DNA. When a Nahua student learns genetics at school, she may conclude that the ability to heal others is in our genes, thus confounding both Western scientific and Nahua explanations. Unless students have the opportunity to explicitly discuss both explanations and understand the rationale behind each one as well as the contexts and moments that are appropriate for each (border crossing), the learning of science may lead to the origin of misconceptions. By conducting this overt comparison between healing and athletic performance, the teacher is facilitating student border crossing between their culture and that of Western science. Example of field notes on lesson 1 (Sept 14, 2012): visit of a healer to the classroom - Student 1: Is healing learned or inherited? - Healer: Well, both, I think both, it is inherited. - Student 2: How do you do it, how do you heal? - Healer: Well, to heal from frightening, I prepare the tea first, or I dip the frightening herb in alcohol and after boiling it, with the vapor I rub it in the body and it comforts the person. - Student 3: Mrs., does anyone else in your family know how to heal or is it just you? - Healer: From my family? Just me. - Student 4: I still want to know, is healing inherited or learned? - Healer: I think it is inherited. - Student 4: But why is that?

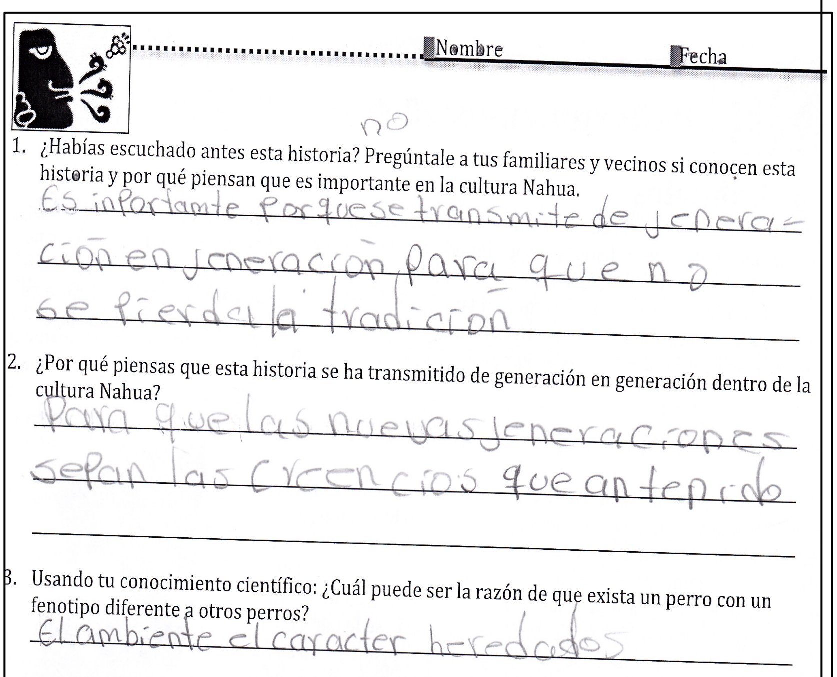
- Healer: Because one can inherit it and then one can learn. (At this point, students continued to ask questions to the healer about how and when she learned to heal others, until the healer had to leave.) - Teacher: Thank you Doña Juanita. Well you all have your own ideas now. Let's go to page 20. There are a few questions related to this visit and with the prior reading. We are going to read them and to try to answer them. Who wants to start reading? (Student starts reading the questions) - Student 5: How is healing similar to athletic performance? - Teacher: I am going to write down your ideas on the board. - Student 6: That both are traits? - Student 7: Inheritance. - Teacher: Inheritance for athletic performance or for healing? - Student 8: For both. - Teacher: What else? - Student 9: That athletic performance can change over time. - Teacher: And what about the ability to heal, does it change over time? What do you think? - Student 10: Yes, it can improve. - Student 11: The healing lady can still learn more about the different ways used to heal others. - Student 12: Yes, her knowledge can change over time. (The class continues to discuss additional questions.) - Student 13 (reading one more question): How are the explanations similar or different from my parents and neighbors about healing to those of scientists that we learned in reading 1,3? - Student 14: My family's explanations are based on what they believe and know and scientists' explanations are based on what they study. - Teacher: So scientists base their knowledge in their studies and their research and your families base their knowledge in their daily experiences and knowledge. Let´s talk again so we gain clarity about what scientists think and what our family and our community think. Scientist say… what do scientist say? That healing is…? - Student 1: That it is learned. - Teacher: Someone else? - Student 2: Does it come from the genes? - Teacher: From genes? Is that what scientist say? Well, and why is it that some people in our community think that healing is both inherited and learned?
Category 2: **Students use Nahua knowledge in science class** Specific moments in the class and in student work or students' explicit statements in interviews where they used the narratives or traditional knowledge of the Nahua culture as a gateway in order to make sense of Western science concepts, thus facilitating the border crossing between the two cultures.

Rationale for this example:
A video was created and showed to students in order to provide them with an opportunity to talk about a popular traditional narrative in Nahua communities, Nahuales. The video was narrated by a young woman of the community in the Nahuatl language. The ways in which students made sense of this video and used it as a gateway for continuing to make sense of the genotype-phenotype relationship (a concept from Western science) is an example of how students' traditional knowledge functions as a resource for learning in the science classroom. The video serves the function of a boundary object because it supported students in connecting a common folk story with which they were familiar to what they had learned about inheritance and population change. In this example, students used their home language, their beliefs (about Nahuales), and their specific forms of interaction (storytelling in the Nahuatl language) in the context of the science classroom as resources, thus maximizing their opportunities to make comparisons with the explanations of Western science. A segment of the discussion as it occurred after watching this video and a student worksheet are shown below as examples of critical events that were coded within this category.

Example: Field notes for Nov 5, 2012 combined with a student artifact

Teacher: Let's see, what was the video about. Juanito, Imanol, and Gregorio [these students were raising their hands].
Juanito: That a man could turn into an animal, that animal could be a donkey or a hen.
Imanol: That some people can turn into animals at night. She told us the story of a man who once saw a huge dog but he kept on walking and then forgot. The next day when going home from work he aw the dog again and he got scared. Next day he grabbed a stick. When he got home no one was there so he went out to look for everyone and he saw the big dog walking away with his donkey that was loaded with corn. The man run towards the dog and started hitting the dog with the stick until the dog screamed "stop hitting me!" and run away. Next day a lady told the man that one of their neighbors was badly beaten and recommended that he would go visit his "compadre" to find out what happened to him. That way, the man realized that his "compadre" was a nahual.
(The teacher then asked one student from each of the remaining groups to add to the story and share what he or she understood from the video and knew about it.)
Teacher: Why is this story important in the Nahua culture?
Silvana: Because it is told by grandparents.
Daniel: It has been told generation after generation.
Ronaldo: It is part of our traditions.
Teacher: Ok, so what is this story trying to explain?
Laura: Why there was such a big dog stealing a donkey.
Teacher: Ok, and stories of nahuales in general, what do you all think those explain?
(There is a few seconds of silence.)
Teacher: Not all at the same time! Ok, you have heard many stories of Nahuales, what is common to those stories?
Yareli: There is always an strange animal in those stories.

Teacher: Ok, I see. Would you agree if I say that in all those stories there are animals with unusual traits?
Yareli: Hmmm, yes, I guess so.
Teacher: What about the others?
Christopher: Yes, the animals in the stories are always somehow different to normal animals.
Teacher: What kind of explanation do you think scientists would give in the same case? If they find an animal that is somehow different to other animals of its kind?
Laura: That it has a different phenotype?
Teacher: What do other people think?
Cesar: Maybe it has a gene that it received from its grandparents and is showing in its phenotype, but it looks different than its parents and other animals in the same area.
Teacher: Onteresting, I am not 100% clear though. Can you or someone else please tell us more about this idea that an animal may not show its parents genes?
(The conversation continues and students discuss the nature of recessive genes by referring back to the pedigrees that they had previously completed. During the class that followed this discussion, students worked in groups and produced comparative charts followed by questions that required them to use both their traditional knowledge and Western science knowledge.)


Nombre Fecha

no

1. ¿Habías escuchado antes esta historia? Pregúntale a tus familiares y vecinos si conocen esta historia y por qué piensan que es importante en la cultura Nahua.
Es importante porque se transmite de jenera-
ción en jeneración para que no
se pierda la tradición
2. ¿Por qué piensas que esta historia se ha transmitido de generación en generación dentro de la cultura Nahua?
Para que las nuevas jeneraciones
sepan las creencias que an tenido
3. Usando tu conocimiento científico: ¿Cuál puede ser la razón de que exista un perro con un fenotipo diferente a otros perros?
El ambiente el caracter heredados

1. Have you heard this story before? Ask family and neighbors whether they know this story and why it is important in the Nahua culture.

It is important because it is passed on generation after generation so tradition is not lost.

2. Why do you think this story has been passed from generation to generation in the Nahua culture?

So new generations know about the beliefs they have had.

3. Using your scientific knowledge: what could be the explanation for this dog with a different phenotype from other dogs?

The environment and inherited traits

Category 3:
Students use Western science knowledge to make sense of social issues that affect their lives
This category refers to instances in the class and in student work or to students' explicit statements in their interviews where they used the concepts that they learned with regard to inheritance and natural selection in order to critically analyze situations from outside of the

classroom that affect their lives.

Rationale for this example:
The following excerpt from my field notes refers to a case in which other group of indigenous people were denied health insurance because of claims that inherited diabetes type II was prevalent in their community. After analyzing this case, students used their knowledge that the traits that human beings express are influenced both by their genes and by the environment in which they live (Western science knowledge). Students related to the experience of discrimination of the Havasupai and shared their own experiences, concluding that genetic testing should not be used to discriminate against them, the Havasupai, or any other group of people. This example shows how students became engaged in using their scientific knowledge when the case under discussion was directly related to their lives in a meaningful way.

Example: Field notes for Oct 3, 2012 combined with a student artifact

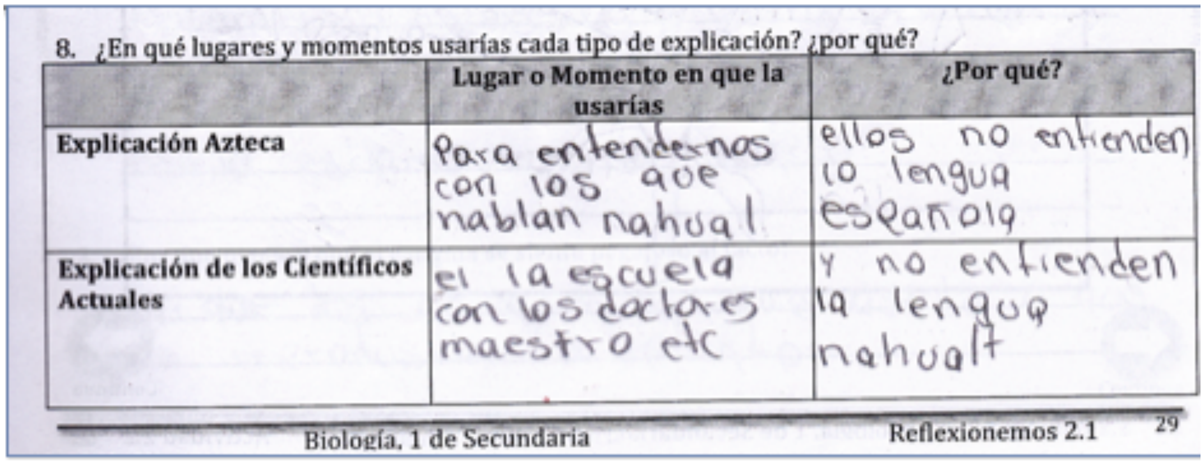
- The teacher asks all of the students to read reflection 3.1 in their teams. While they work on making sense of the reading, she walks around and stops by every group, observing what they are doing. Students are on task.
- (I am listening to the interactions of the group that is closer to where I am sitting.) Fabiola is discussing and sharing her understanding of the reading with the team, insisting that malnourishment needs to be part of the evidence and that the explanation provided in the worksheet is wrong. Alfonso replies by saying that what is important in the reading is that the Havasupai were discriminated against by the health insurance companies, but he is not sure where to use that information because he does not understand what evidence is. Other members of the group seem equally confused.
- The teacher addresses the whole class and asks each group to share its ideas first (before going into critiquing the explanation presented in the student guide).
- Nieves raises her hand immediately and says that diabetes type II is an inherited disease.
- Ruben A replies, saying that malnourishment is making the Havasupai sick and not only their genes. He adds, "Not everything that is true is evidence." The other members of his team nod.
- Students in other groups seem confused by this statement, and Alfonso asks (now so all the class can hear), "Teacher, what is evidence?"
- The teacher goes to the board and writes the claim in the students' worksheet. Then she says that evidence is what supports the claim, a proof. She asks, "Is the picture in the reading evidence?"
- Students do not agree.
- The teacher says, "Look at your facts sheet. What information there supports your claim? Ruben was right that not everything that is true is evidence but only those pieces of information supporting the claim. Continue discussing in teams and use your facts sheet now."
- In one group, Fabiola and Lisbeth disagree with Alfonso that the right evidence to support the claim (diabetes type II is inherited among the Havasupai) was the high level of consanguinity among the Havasupai. Fabiola and Lisbeth insist that consanguinity is not included in all the

risk factors for diabetes type II included in the facts sheet. Alfonso raises his hand, calling the teacher. The teacher approaches the group and Alfonso asks (while the other three members of the group watch attentively), “Teacher, I do not understand. Diabetes type II is an inherited trait. Why isn’t that included in the risk factors of the facts sheet? I mean, the companies should not deny insurance but they are kind of right, no?” (Fabiola and Ruben C shake their heads.) The teacher says, “Remember when we talked about athletic performance? We discussed whether it was an inherited or acquired trait. What did we conclude?” Alfonso says, “It is both because you can inherit some stuff but you have to train too.” Teacher says, “How is that similar to diabetes? Can you see the similarity? Think about it and try to reach agreement.” She leaves for a different group. Ruben C tells the team that the risk factors are part of the environment and Alfonso nods. He starts reading what Lisbeth wrote in her worksheet and starts working on his own.
- The teacher continues having small conversations with different groups. After 17 minutes she goes to the front of the classroom and ask the class to be silent. Then she asks, “Ok, we have discussed what is evidence. So do the insurance companies have evidence to deny insurance to the Havasupai only based in the fact that diabetes is inherited?”
- Carmen says that the facts sheet mentioned poverty and malnourishment as risk factors for diabetes and those were not included in the companies’ explanation so they were wrong.
- Fabiola eagerly raises her hand. She says that the Havasupai were discriminated against, as she was discriminated against when she went to the city with her mom and people looked down at her mom when she was speaking in Nahuatl.
(About 10 students are raising their hands waiting for their turn to participate.)
- Sergio says that the Havasupai are being discriminated against because they are fat and sick.
- Ruben A says that what is just is to provide help to all families with inherited diseases.
- Nieves says, “When using genetic testing we need to respect everyone regardless of their clothing.” [The use of traditional garments by Nahua people is heavily discriminated against in that region.]
- Carmen says that the insurance companies were wrong because people get diabetes because of their genes and their environment so they have to give insurance to the Havasupai.
(Bell rings.)
- The teacher says, “Ok, it seems we understood. As homework you will have to use your scientific knowledge to write recommendations for the secretary of health of Arizona, where the Havasupai live. We will discuss this on Friday.”
(Class dismissed.)

Category 4:
Difficulties in border crossing between cultures
This category refers to instances in which students expressed through their participation in class (registered in the field notes), their interviews, or their writing in their notebooks that Nahua knowledge belongs solely to their communities and that science knowledge belongs only to the school.

Rationale for this example:
The following student worksheet belongs to the activity where students compared how Aztecs

and Western scientists explain the fact that we find chocolate bitter. This worksheet shows that the student establishes a separation where the two types of knowledge are used exclusively in one context. The student adds that, because of language science cannot be used in their community and traditional knowledge cannot be used at school because people would not be able to understand. This is an example of a difficulty in border crossing between cultures, where a student compartmentalizes her or his cultural knowledge and school knowledge and understands the two forms of knowledge as incompatible.



8. ¿En qué lugares y momentos usarías cada tipo de explicación? ¿por qué?

	Lugar o Momento en que la usarías	¿Por qué?
Explicación Azteca	Para entendernos con los que hablan nahual	ellos no entienden lo lengua español
Explicación de los Científicos Actuales	el la escuela con los doctores maestro etc	y no entienden la lengua nahualt

Biología, 1 de Secundaria Reflexionemos 2.1 29

	Place or moment where you would use it	Why?
Aztec explanation	*To communicate with those who speak Nahuatl*	*They do not understand the Spanish language*
Explanation from current scientists	*At school with doctors, teachers, etc.*	*And do not understand the Nahuatl language.*

The selected critical events were organized chronologically using the software NVivo 10 (QSR International Pty Ltd, Victoria, Australia) in order to create a narrative account of the phenomenon of border crossing as it occurred while learning about inheritance and natural selection within the contextualized unit. This deductive approach allowed for the location and analysis of data specifically related to border crossing among a vast corpus of student worksheets, running records, and student interviews for the purpose of finding patterns within and across events of border crossing (Derry, et al., 2010). To select these critical events and to document this process and proceed to coding, I had to search the complete corpus of data several times in order to find representative instances of border crossing.

3.2.5. Clustering of Categories Using Jaccard's Coefficient on Coding Similarity

I used NVivo in order to facilitate the coding process and to more easily manage data and categories. I used cluster analysis, which is one of the tools offered by this software to support the researcher in seeing patterns and relationships in the data. The cluster analysis tool allows for the generation of a diagram that clusters selected nodes together if they code many of the same sources.

Because most of my sources correspond to artifacts that were created by a single student or to individual student interviews, categories were closed in terms of the similarity of the sources that they contain by using a coefficient of similarity. Using Jaccard's coefficient, NVivo calculates the similarity index between each pair of categories, groups the categories into a number of clusters, and uses a farthest neighbor hierarchical clustering algorithm in order to generate a complete dendogram with all of the categories.

The closer two categories are, the more the artifacts of the same students were coded in both categories. This is only an exploratory technique that provides a general sense of the patterns of coding of all of the sources in this analysis.

3.2.6. Analysis of Pre/Post-Test Learning Gains

This analysis was aimed at understanding the quantitative learning gains that can be derived from learning science within a contextualized unit that is culturally relevant to indigenous students. In order to determine the effectiveness of the contextualized biology unit, a pre/post-test was given to students in the two classrooms in which the contextualized unit was enacted. Identical tests, which were originally designed as part of the unit (Reiser & Krajcik, 2012), were administered before and after the enactment of the contextualized science unit. Scores represent the key variable "student understanding of natural selection." The pre/post-test measure consists of 15 multiple-choice items with a maximum possible score of 15 points. Items were created in order to measure students' understanding of natural selection across three cognitive levels—low, medium, and high.

3.2.5.1. Data Analysis

Correct responses were tallied for the multiple-choice items, but only for those students who completed both pre- and post-tests. A matched two-tailed t-test analysis was conducted in order to compare the pre-test and post-test results in the two classrooms and to understand the effect of the contextualized biology unit on student learning gains.

CHAPTER 4: PROCESS OF CURRICULAR CONTEXTUALIZATION

4.1. Introduction

As explained in Chapter 3, the approach to contextualization used in this dissertation was one that combines perspectives in the learning sciences, specifically situated cognition, with research on cultural cognition relevant to the learning of inheritance and natural selection (teleology and essentialism), and with perspectives deriving from cultural studies that seek to understand culturally based practices and understanding of the world. All of these perspectives are interconnected through the frameworks of Culturally Relevant Pedagogy (Ladson-Billings, 2006) and Cross-Cultural Science Education (Aikenhead, 2001). This interdisciplinary framework served as the basis for the design of contextualization principles based on real world examples (Krajcik, et. al., 2007, 2008) that were incorporated into the IQWST science unit on inheritance and natural selection.

The use of this interdisciplinary framework to contextualize the IQWST science unit made possible to account for the ideas and experiences that Nahua students bring to the classroom; that is, their culturally-based psychological patterns of reasoning underlying those ideas, and their cultural practices, traditions, and societal structures that render those ideas meaningful for the Nahua people. This approach ensures that the contextualization of the unit is culturally relevant, meaning that it is guided by the students' real world experiences embedded in their culture and not by the researcher's biases and interpretation of what might be relevant for a particular group of students, in this case, Nahua students in Veracruz.

In the following sections I will describe how the results of exploring culturally-based psychological patterns of reasoning, as well as Nahua cultural practices, traditions, and societal structures, served as the basis for conceptualizing each one of the contextualization principles and for designings the specific examples that served to illustrate the contextualization principles in the science unit.

4.2. Contextualization Principles based on Culturally Based Reasoning Patterns: Teleology and Essentialism

The tendencies to explain phenomena by reference to function (Kelemen & Rosset, 2009), and to see species as unchanging and stable, with all the members of a species sharing some unobservable, underlying quality that causes its observable characteristics (Gelman & Rhodes, 2012), teleology and essentialism respectively, have been shown to underlie the development of misconceptions or naïve theories about natural selection (Rosengren & Evans, 2012). However, whether teleology and essentialism influence the Nahuas' understanding of natural selection has not been established since no studies have been conducted with Nahua population or with other Mexican groups, and therefore it is not possible to assume that Nahua students would exhibit these same biases.

Because of the significance of these biases in understanding natural selection, and taking into account that the IQWST unit that was contextualized in this study is focused on teaching the concepts of inheritance and natural selection, it was necessary to explore whether adults and middle school students in the Nahua community exhibited these biases and to what extent.

I hypothesized that contextualizing the biology unit using this information specific to Nahua students would facilitate the Nahua students' learning of natural selection and inheritance, because the psychological roots of their alternative conceptions, if present, would be uncovered. This information was used in the design of the principles that served to contextualize the unit for the specific learning needs and worldviews of Nahua students, thus increasing the relevance of the unit for them.

4.2.1. Teleological Reasoning Patterns in the Nahua Community of Tequila, Veracruz

In the case of reasoning about the natural world, the teleological bias involves the tendency to believe that organisms possess their current traits because those traits perform functions that help survival (Kelemen, 2012). This type of reasoning focuses on function as the sole explanation for traits evolution, ignoring events such as mutation, competition, and differential reproduction rate. In line with this, students who are biased towards teleological thinking tend to explain natural selection in terms of the needs of a an organism rather than as the change in the frequency of traits within a population due to the comparative advantage (differential reproduction and survival) that certain traits have over others in a given environment.

To better understand whether adults and 7th grade students in the Nahua community of Tequila exhibit a teleological bias and whether this bias is promiscuous (Kelemen, 2009) or domain specific (Keil, 1995), I examined the teleological explanations that were freely provided by the participants when domain, property type, and scope (generic vs. specific phrasing) of the information to-be-explained were varied. This analysis allows understanding the extent to which students and adults over-rely on teleological explanations, if they do. Building on prior studies, I formulated three hypotheses:

1) In the Nahua community both adults and children will provide more teleological than causal responses across domains –animals, plants, non-living natural kinds (NLNK) - (promiscuous teleology). This hypothesis is based on research indicating that individuals with low educational attainment from non-Western communities are significantly more likely to explain biological and non-biological properties with reference to function (Casler & Kelemen, 2008). This over-reliance on

teleological reasoning when thinking about living organisms and NLNK may derive from limited knowledge about the causal processes that give rise to organisms and NLNK's features (Kelemen, 1999, 2003).

2) Teleological explanations would be more frequent in explanations of static features (e.g. pigeon's wings) as opposed to actions (e.g. pigeon's ability to fly) because the causal processes that give rise to static features are often relatively inaccessible, technical, or complex, individuals rely on teleological explanations in those cases (Hollander, Gelman & Manczak, 2011).

3) Questions regarding features of a category (generic phrasing) would lead to a greater emphasis on teleological explanations because prior causes are variable across members of a group (e.g., within a group of dogs, particular dogs may bark due to a varied set of causes), whereas questions regarding features of an individual (specific phrasing) would lead to a greater emphasis on causal explanations (Cimpian & Markman, 2009; Hollander, et. al., 2011).

These hypothesis were tested by conducting two repeated measures ANOVAs, one for responses coded teleological and the second for responses coded causal (see coding protocol and methods in Chapter 4). Contrary to what I predicted based on the literature (hypothesis 1), adults and students provided more causal than teleological responses, and adults provided more causal responses than students for both action and static features of plants, and for static features of NLNKs (Fig. 4.1 and 4.2). The differences between students and adults in the frequency of teleological responses are domain dependent, with students providing more teleological responses for the plant domain. Participants did not show a promiscuous teleology response pattern since there is a significant effect for the domain factor for both teleological ($F(2,152) = 12.97$, $p < .01$, $\eta^2_p = .77$) and causal responses ($F(2,152) = 12.97$, $p < .01$, $\eta^2_p = .56$). The effect sizes (partial eta squared -η^2_p-) are large in the two cases, accounting for 77% of the effect + error variance for teleological responses and for 56% in the case of teleological responses. It is worth noting that both students and adults selectively provided teleological responses as a function of domain, regardless of their low educational attainment, contrary to Casler & Kelemen's (2008) findings for low-schooled non-Western adults. These patterns of response may be due to the deep ecological knowledge of Nahuas, given the resemblance of these results with those found for schooled adults in Western societies who are usually exposed to several years of science education (Keil, 1995; Kelemen, 1999; Lombrozo, Kelemen, & Zaitchik, 2007).

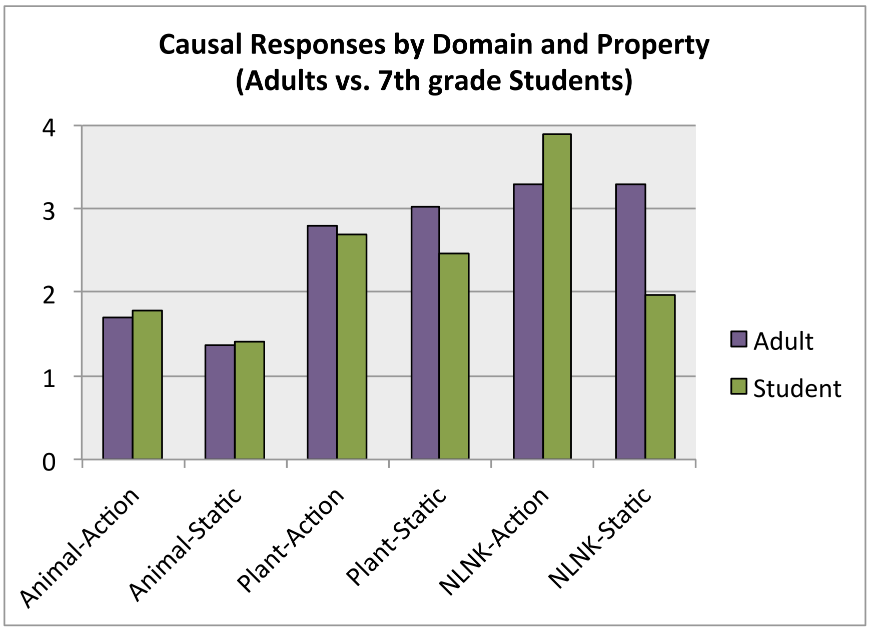


Figure 4.1. Causal responses of adults and students

The scores presented in Figures 4.1 and 4.2 correspond to the mean numbers of teleological and causal responses for each participant. The numbers of teleological and causal responses were tallied, separately for each domain and property. Thus, each participant received 6 scores (3 domains x 2 properties), each score potentially ranging from 0-4 (because there were 4 items per domain x property block). Age group (adults vs. students) and scope (generic vs. specific phrasing) were between-subjects variables, and domain and property were repeated-measures variables.

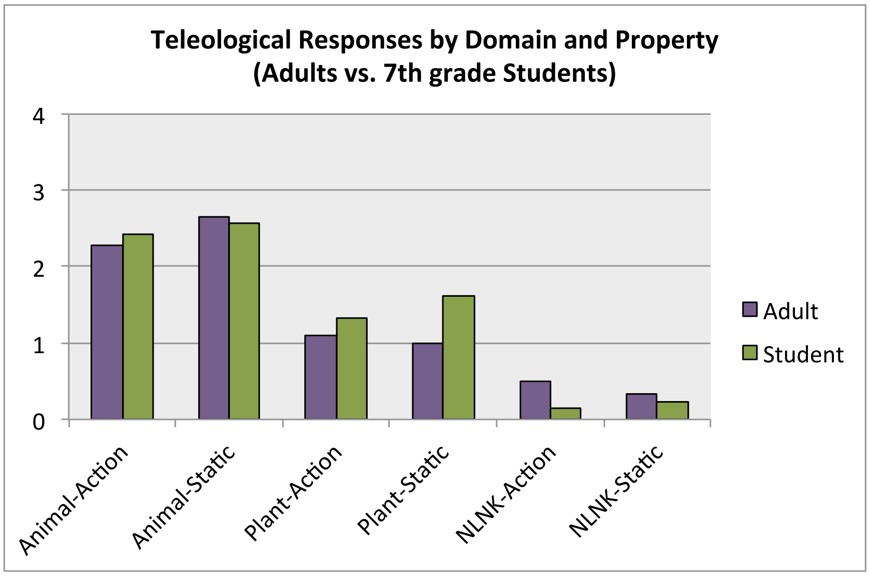


Figure 4.2. Teleological responses of adults and students

On the other hand, I predicted that adults and students would selectively use causal explanations relatively more often for action properties than static properties (hypothesis 2), as described in the literature, actions as opposed to static properties, are understood within more accessible causal theories. As predicted, property type interacted with domain ($F(2,152) = 12.632$, $p < .001$, $\eta_p^2 = .143$); and with domain x age group ($F(2,152) = 12.976$, $p < .001$, $\eta_p^2 = .146$). However, post-hoc analysis indicates that both adults and students provide significantly more causal answers for active properties only of the animals ($p = .002$) and NLNKs ($p = .000$) domains, but not of plants. Plants show the opposite pattern (more causal responses for static features), but this pairwise comparison was not significant. This pattern may be attributed to the vast knowledge about plants exhibited in this community, which may obviate the need to invoke teleological explanations when thinking about static features of plants such as oak tree bark, or corn kernels. Similarly, the results do not support the prediction that students and adults would use teleological explanations more often for static properties than for action properties, which may indicate that adults and students in this community have traditional knowledge about static features of plants, animals, and NLNKs that they use to formulate causal responses instead of privileging teleological responses for static features. This does not necessarily mean that the causal responses provided by adults and students are accurate in terms of Western science knowledge standards, but these responses are not predominantly purpose-driven.

The remaining significant effects involved scope (hypothesis 3, whether the question concerned a category or an individual). Scope showed to significantly interact with age (student vs. adult) x domain x property (teleological responses: $F(1, 152) = 7.53$, $p < .01$, $\eta_p^2 = .09$; causal responses: $F(1, 152) = 4.27$, $p < .05$, $\eta_p^2 = .05$) despite the small effect size and the marginal significance for causal responses. As predicted, both students and adults provided more teleological responses for categories (questions with generic phrasing) than for individuals (specific phrasing). However, as revealed by post-hoc analysis, this pattern of response was only significant for the generic condition, in which adults provided slightly more teleological answers than did students for active features of NLNKs ($p < .05$); and for the specific condition where students provided more teleological answers than did adults for active and static properties of plants. In the case of the active features of NLNK, both the mean scores of adults (0.6 out of a possible 4.0) and students (0.2 out of 4.0) are very low, indicating that despite the statistical significance of this interaction, most participants privileged causal responses for this domain and property. These results only partially support hypothesis 3, because features of a category (generic phrasing) led to more emphasis on teleological explanations only for plants with a marginal significance.

Taken together, the results indicate that students are relatively more teleological than adults except for the NLNK domain. Overall, both students and adults provided more teleological responses for animals, but more causal responses for plants and

NLNKs. These overall results challenge prior studies with the universalizing suggestion that humans are predisposed to teleological reasoning (Kelemen, 2012; Shtulman & Calabi, 2012). In the extant study Nahua adults and students sampled did not privilege teleological reasoning over causal reasoning for the domains of plants (a living kind) and non-living natural kinds. In this population there is a modest over-reliance on teleological reasoning only for the animal domain. Taking into account the low educational attainment typical of the adults in this community, and in particular of the adult participants in this study (57% completed elementary, 20% completed middle school, 10% completed high school, and 12.5% completed a bachelor's degree), it is unlikely that exposure to Western schooling and science education can explain the preference for causal reasoning, as other studies have argued (Kelemen, 1999; Casler & Kelemen, 2008). These prior studies have found that adults with little Western schooling tend to endorse teleological types of reasoning, which has been interpreted as evidence that these individuals mistakenly believe that natural kinds, like artifacts, were designed to 'exist for a purpose'. A limitation of this work, however, is that it has not accounted for the ecological expertise of non- Western educated indigenous people, which may be a potential explanation for the reasoning pattern found in this Nahua community.

Offering an alternative perspective, more recent studies on teleological reasoning consider the ecological knowledge of indigenous peoples by proposing that the teleological stance may not index a deep rooted belief that nature was designed for a purpose, but instead may reflect an appreciation of the perspectival relations among living things and their environments (Ojalehto, Waxman & Medin, 2013). This perspective offers an alternative explanation for why indigenous groups generally exhibit a promiscuously teleological reasoning, by focusing on their ecological knowledge instead of understanding this type of reasoning as a result of low educational attainment. However, the results of the present study do not support either the idea that deep ecological knowledge and understanding of relationships among living things leads to a promiscuous teleology, at least for the sampled Nahua community. The results presented here suggest that there is no comparable consistency in the functional perception of animals, plants, and NLNKs across cultures, or even across indigenous groups that engage in relational ways of thinking about living kinds. The assignation of function to living kinds and NLNKs seems to be a matter of cultural convention (Atran, 1995; Medin and Atran, 2004).

The present findings have implications for the design of contextualized curriculum focused on teaching the concepts of inheritance and natural selection are important. Although it is fundamental to understand the cognitive constraints that limit or facilitate the learning of complex concepts (Rosengren & Evans, 2012), it is necessary to acknowledge that these constraints vary across cultures. In the case of teleological reasoning, this constraint has been shown to negatively impact the understanding of evolutionary constructs by US-based students (Nehm & Ridgway, 2011); however, there is no base to generalize the reasoning patterns of this population to humanity at large (Medin & Atran, 2004). In other words, it is not reasonable to assume that lay adults and children in other societies will also exhibit promiscuously teleological ways of thinking and therefore will face important challenges when learning about evolutionary constructs such as inheritance and natural selection. In the case of Nahua students, the preference for causal reasoning in the plant domain can be seen as a culture-specific cognitive constraint, which has the potential to facilitate students' understanding of natural selection and in heritance.

4.2.1.1. Contextualization Principles based on the Results of the Teleology Interview

Several studies support the interpretation that the preference for causal thinking in relation to plants and NLNK in the Nahua community may be due to the expertise of indigenous individuals to reason about the natural world (Atran, 1995; Ojalehto, Waxman & Medin, 2013). However, there is still significantly higher use of teleological reasoning for animals in this community. Moreover, adults and 7th grade students did not demonstrate different patterns of reasoning from each other, suggesting that these types of reasoning (more causal for plants and NLNKs, and slightly more teleological for animals) are entrenched in the Nahua culture. Given these types of culturally based knowledge and reasoning, they should be used as a resource to facilitate students' learning (Agbo, 2004; G. Aikenhead, 2001; Castagno & Brayboy, 2008; Ladson-Billings, 2006; Ladson-Billings, 1995) and for the development of curriculum that is relevant for Nahua students.

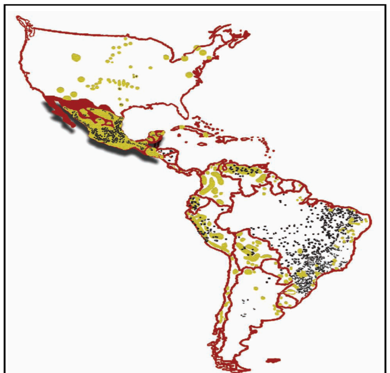
Consistent with the above, two types of principles were created to guide the design of specific examples along the unit that would support the learning of the Western science concepts of inheritance and natural selection relevant for students.

Principle 1: Using students' culturally based knowledge of plants as a context to understand complex concepts such as artificial selection (the difference in reproductive success is driven by selection is imposed by humans).

The examples introduced to contextualize the unit that highlight traditional Nahua knowledge or experiences as a way to facilitate the learning of Western science concepts were called "Reflexionemos" (Let's Reflect). One example of this principle is the creation of a text where students had the opportunity to learn how the knowledge and agricultural technologies of Mesoamerican and South American indigenous groups enabled them to selectively breed corn into most of the modern varieties we know. I composed this text in Spanish -as that is the language of instruction in Mexican middle schools- based on a technical report on corn diversity today and prior to European colonization (Serratos Hernández, 2009). I translated the text into English here for the purposes of making the text accessible to the readers of this dissertation.

Nombre Fecha

Let's Reflect 11.1
Selective Breeding of Corn: Ancestral Knowledge of the Indigenous Peoples of the Americas



Distribution of corn types in the American continent. Green areas: zones where native varieties have been collected. Black dots: currently areas where corn is produced in Latin America.

The relationship between different cultures of the American continent with corn has been established. Even the foundational myths of these civilizations, particularly the Mesoamerican ones, give us information about that close relationship.

The legends where corn is central inspired the development of the peoples and cultures of Mexico. For example, the Olmeca culture was the first human group that started growing corn and creating myths around it. Part of their beliefs included having received the plant of corn from the deity Quetzalcoatl, to derive nourishment from it.

There is diversity of stories and myths among mayas, teotihuacanos, toltecas, mixtecas, and mexicas, but all of them have in something in common: corn is an essential element to sustain human life. For example, the legend of the suns of the Mexicas telling the story of the creation of the world talks about corn, and the maya-quichés have stories about how humans were created out of corn dough. Both those cultures made of corn a core element of their worlds, and those narratives brought unity to a system of beliefs of many Mesoamerican cultures.

On the other hand, in the Andean region of South America, the Inca Empire developed sophisticated agricultural techniques in which corn played a central role. The procedure of selective breeding used by Incas was enough to achieve the great variation in shape and color of the corn varieties of that region. The Incas used some varieties of corn for specific purposes and they flourished thanks to the Inca's advanced agricultural techniques such as terraces, irrigation, planting seeds in furrow, and fertilization. These techniques were also employed by other Andean cultures by the time that the Spaniards arrived to America. In this context, it is not surprising that the greatest numbers of described varieties of corn are in Bolivia and Peru. However, according to the variations within specific breeds of corn, it is in Mexico where we find the greatest variety of corn in the whole world.

By the end of the conquest and at the beginning of the colonial times, there were communities across America that had corn as the core element of their sustainment and culture, which allowed continuity in the interaction between humans and ancestral forms of corn. The historic relationship that indigenous peoples and mestizo peasants have developed with corn has been a fundamental factor to the survival and diversity of corn. This relationship between indigenous peoples and corn has allowed for the survival of 300 types of corn in the American continent.

Indigenous peoples have had and have now a close relationship with corn that has turned indigenous peoples into guardians of the genetic diversity of corn. For example, by revaluing the traditional Mexican agriculture, different scientists and anthropologists have found that there is an association between corn diversity and the ethnic and linguistic diversity of Mexicans. These results led to the conclusion that the differentiation and preservation of corn types is related to language, and therefore with the traditional knowledge used by indigenous peoples to conserve their patrimony by growing and producing "their corn".

Diego Rivera's painting: "Indigenous Boy with Corn Stems"

From a biological perspective, the mechanisms of diversification of corn have been studies to better understand the diversity of phenotypes available to peasants for conducting selective breeding and producing new varieties of corn or conserving existing ones. All the studies about corn and its relationship with traditional agricultural systems show that the management that indigenous peoples give to corn across the American continent is fundamental for maintaining the diversity of this plant.

The diversity and survival of the diversity of corn rests on the traditional knowledge and practices of indigenous peoples. However, this diversity is threatened by economic factors that displace indigenous peoples from their lands, because they see themselves obligated to leave their lands in search for a better quality of life. The destruction of the social fabric in indigenous communities increases the risk of extinction of many varieties of corn by altering a key factor to its survival: the indigenous peoples who grow these corn.

In this context, it is indispensable to step into a new phase in which there is a revaluation of corn in the entire American continent, as a core axis of the defense and sustainability of the indigenous peoples' territories. With all the evidence we have analyzed thus far, it is demonstrated that the diversification of corn is a process that occurred in several regions of the continent and involved most pre-Hispanic civilizations. Therefore, it is necessary to revalue the meaning of corn in the continent.

We can say that corn is the core axis of the life of many peoples' in the American continent and should be considered an emblematic crop. The protection of corn should be a responsibility of all the peoples in the American continent, regardless of the current borders between countries.

This reading emphasizes the agricultural practices that gave rise to corn varieties, and explains the process of selective breeding using a language based in mechanisms and causal processes that is part of the traditional knowledge of students in this community. The emphasis is not in function, but in the processes and practices that originated that diversity. In this way this reading capitalizes on the preference of Nahua students for causal reasoning when thinking about plants to introduce the complex concept of the origin of corn diversity. The reading also takes advantage of the Nahua students' traditional knowledge about the cultivation of corn, to introduce the Western science explanation for this process. It does so without devaluing students' cultural knowledge, but instead, highlighting its value. Questions focused on the similarities and differences in the ways that Western science and Nahua tradition explain the process of artificial selection were suggested after completing the reading. These questions were designed to engage students in meaning making on the basis of border crossing between the two cultures, which will be discussed in section 4.3.

Principle 2: Reflecting on teleological types of reasoning when applied to animals through the evaluation of inaccurate evidence-based explanations. The strategy of reflecting on teleological types of reasoning or making them visible to students is suggested in the literature of evolution teaching (Evans & Rosengren, 2012; Kampourakis & Zogza, 2009) to facilitate students' understanding of the causal mechanisms behind this process. Because the IQWST unit already included the construction and evaluation of evidence-based explanations as one of its features, I used this to provide opportunities for students to evaluate teleological explanations regarding animals, using their scientific knowledge. The example below provided students with data and information about population change in ladybugs (Fig. 4.3).

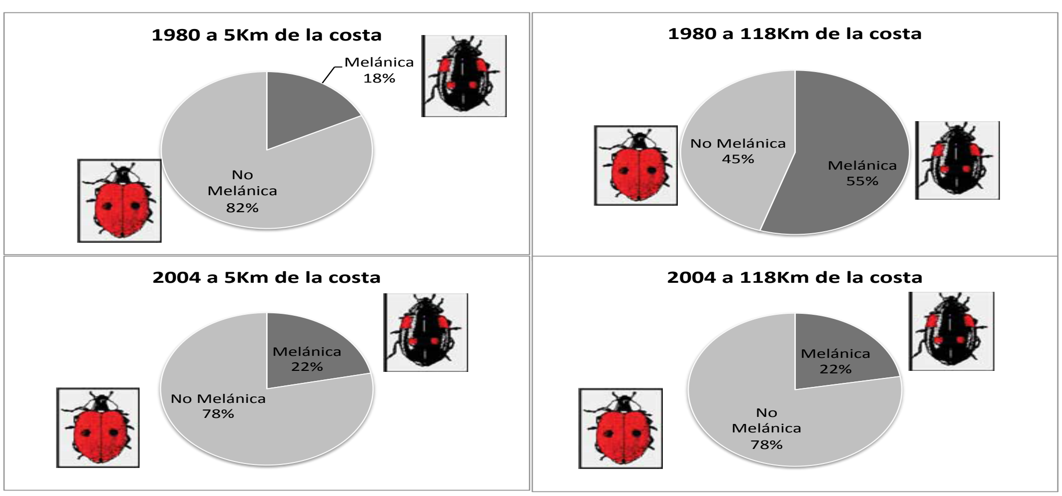


Figure 4.3. One source of data provided to students to evaluate two explanations.

Students were asked to use all the information they had to decide whether the two following explanations were accurate.

Why did the distribution of ladybugs change?

LUPE		ANGEL	
Claim	*Melanic ladybugs living far from the coast realized that the air was warmer and decided to start reproducing, because now they could stay more active and obtain food.*	**Claim**	*Melanic ladybugs were dark so they could stay active in cold places. Now that the climate changed they do not need to be dark anymore, but they need to protect themselves from predators, so they became red.*
Evidence	*In 1980 45% of the non melanic ladybugs lived far from the coast, now that it is warmer 78% of the non melanic ladybugs live in this place.*	**Evidence**	*In 1980 45% of the non melanic ladybugs lived far from the coast, now that it is warmer 78% of the non melanic ladybugs live in this place.*

Figure 4.4. Explanations based on teleological reasoning offered to students for evaluation.

The two explanations (Lupe and Angel's) offered to students to evaluate in this examples (fig. 4.4) were teleological and centered in population change. Lupe's one describes ladybugs as autonomous and purpose-driven in ensuring their survival, a common misconception among students and lay adults, while Angel's explanation endorses a transformational view where individual organisms change in response to environmental changes, also a common misconception (Settlage, 1994; Bishop & Anderson,1990; Sinatra, et al., 2003). Students were asked to evaluate these explanations, discuss in small groups, and construct new explanations that could accurately explaining the differences between Lupe's and Angel's explanations. This example illustrates how students were presented with teleological reasoning as a way for them to understand types of teleology that are unproductive when explaining natural selection and population change.

Finally, because generic phrasing only had a marginal effect on the frequency of teleological responses for plants, I did not introduced changes to the unit that would emphasize specific phrasing. A change like would require to refrain from phrasing examples and explanation in terms of categories (e.g. "humans", "corn") to focus on individuals, which would conflict with students' ability to comprehend the idea of change and variability within a category (species), an idea that students need to master to understand natural selection. Taking into account the marginal significance of generic phrasing on teleological responses, which was present only for plants and not for all domains, it did not seem efficient to introduce changes to the unit based on this result.

4.2.2. Essentialist Reasoning Patterns in the Nahua Community of Tequila, Veracruz

Apart from teleology, essentialism has also been reported to interfere with the understanding of natural selection (Evans & Rosengren, 2012; Shtulman & Schulz, 2008). Because essentialist reasoning leads to believe that all members in a species share underlying common features it tend to conflict with the idea of within-species variability. Natural selection operates based on the variability of traits in a population, only some traits in a population are favored in a given environment, and the probability of these favored traits to be passed on to the next generation increases. Understanding this idea requires a flexible understanding of what a species is: accepting that members of the same species may vary in terms of multiple traits, but remain members of the same species. In contrast, essentialist views of species where members of a species are seen as sharing deep similarities and an underlying reality that includes internal or invisible properties (Gelman & Rhodes, 2012) might impede the understanding of natural selection because an essentialist bias imposes difficulties for the student to understand within-species variability, which is the raw material of natural selection.

Shtulman and Schulz (2008) designed a task to assess the degree to which participants conceptualized species as collections of unique individuals, that is species as populations of diverse individuals (consistent with modern biology), or as an homogenous entity where individuals of a species share an underlying "essence". These authors discovered that subjects in a U.S. sample ranging between 4 to 40 years old rejected the idea that within-species variation is both prevalent and probable. This, of course, represents a challenge for the learning of natural selection as the mechanism of biological evolution.

In the present study I modified the task designed by Shtulman and Schulz (2008) by replacing the mammals they used with other mammals familiar to Mexican Nahua students (e.g. I replaced the kangaroo with a pig), and I also included a new domain (plants), to understand whether Nahua students accept the idea of within-species variation for animals and plants.

I also formulated three hypotheses based on prior studies on essentialist thinking about biology across cultures (Shtulman & Schulz, 2008; Medin & Atran, 2004; Gelman, 2003; Shtulman & Calabi, 2012; Atran, Medin, and Ross, 2002).

1) Adults will recognize actual variability of species-specific properties significantly more often than students, because of their increased experience with the

biological world (Shtulman & Schulz, 2008) and their deep knowledge of plants and animals of their context.

2) Both adults and children will be likely to reject potential variability for internal and external species-specific properties, and may be more likely to admit potential variability for behavioral species-specific properties. Biological essentialism, the idea that species are discrete homogeneous units, has been demonstrated to occur across cultures (Medin & Atran, 2004) and across ages (Gelman, 2003). This essentialist bias when thinking about species lead individuals to think that every member of a species has the potential to grow and develop only those properties associated with that species, making the group homogenous (Shtulman & Calabi, 2012; Shtulman & Schulz, 2008).

3) Both adults and students will recognize variability of external and internal properties significantly more often in plants than in animals, because of the rich knowledge base this group has about plants (derived from agriculture and traditional medicine mainly). Expertise in a domain has been demonstrated to result in a concern with ecological and morpho-behavioral relationships in other indigenous groups such as the Guatemalan Maya Itza', that lead individuals of this group to engage less often in essentializing biological taxa (Atran, et al., 2002).

These hypotheses were tested by conducting four repeated-measures ANOVAs:

- Two ANOVAs for responses that admitted actual variability (one for behavioral, internal, and external properties of animals, and one for internal and external properties of animals and plants).
- Two ANOVAs for responses that admitted potential variability (one for behavioral, internal, and external properties of animals, and one for internal and external properties of animals and plants).

Contrary to what I predicted based on the literature (hypothesis 1), adults and students did not exhibit significant differences in their average number of responses judging external, internal, and behavioral properties variable for both animals and plants (Fig. 4.5).

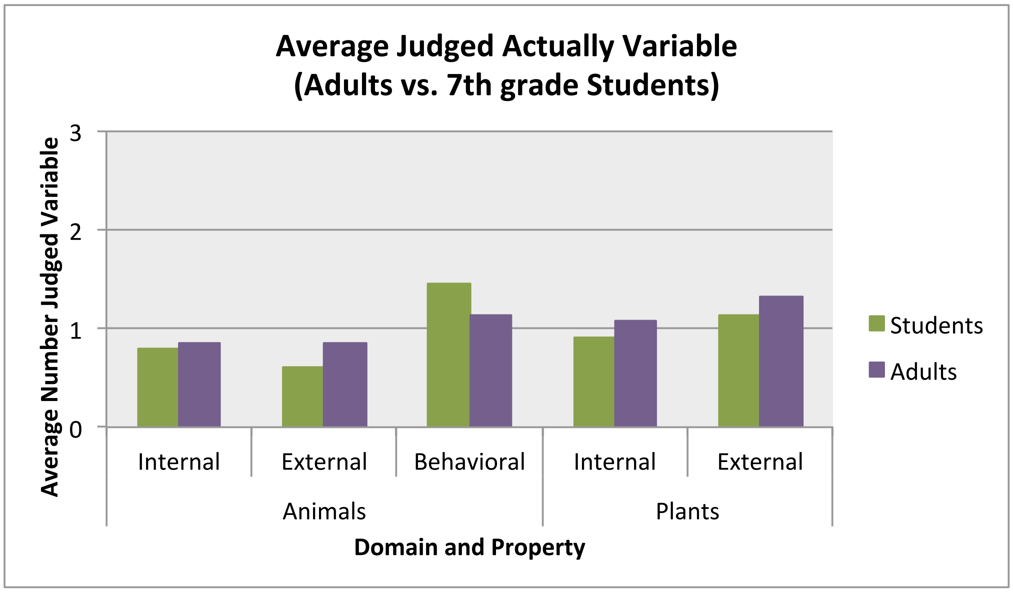


Figure 4.5. The average number of behavioral, external, and internal properties (out of 3) judged actually variable by each group of participants.

More specifically, there was no significant age group effect for the domain x property interaction when comparing the responses for internal, and external properties of animals and plants ($F(1,78) = 0.25$, $p = .61$, $\eta^2_p = .003$). There was only a significant age group effect for the behavioral properties of animals, where students tended to more frequently admit actual variability for behavioral properties of animals ($F(2,156) = 0.25$, $p < .05$, $\eta^2_p = .045$). However, the effect size for this interaction (age group x property) was very small. This indicates that students viewed the distinction between behavior and anatomy as more meaningful than the distinction between external anatomy and internal anatomy, presumably because they may have more knowledge about animal behavior than animal internal and external anatomy. Aligned with these results, there was no significant difference in the average number of external and internal properties of animals that each group (students and adults) judged actually variable.

These results resemble Shtulman & Schulz' (2008) findings for adults with a low comprehension of Western science ideas such as selective pressure, individual differences as a result of random processes, and aggregate differences among successive generations of the same species as the result of differential survival. Understanding these concepts requires the ability to reason about changes occurring at the level of the entire population of a species, a type of reasoning privileged by Western Science to understand biological evolution, suggesting that individuals judging external, internal, and behavioral properties variable with high frequency become more easily engaged in thinking about the whole taxon or population (all pigs) and use it as the base to evaluate variability within the whole category. However, several indigenous cultures privilege relational/ecological reasoning, where the survival and characteristics of an organism are judged in a context dependent manner (Atran, 1998; ojalehto, Waxman, & Medin, 2013). Therefore, it may be that Nahua adults and students do not engage in thinking about the "all pigs" (all the pigs in the world), but only those pigs that they have actually seen, narrowing their range for admitting within-species variability. This idea is supported by the types of justifications adults and students provided when not admitting actual variability for a given property (Fig. 4.6). Both students and adults provided significantly more property-based justifications (appeals to the undesirability or implausibility of changing a particular, e.g. "a pumpkin with a different type of seed could not grow and produce fruit") than species-based justifications (appeals to the uniformity of species members, e.g. "a pumpkin cannot have a different type of seed because all pumpkins are the same) $X^2[1, N = 80] = 6.04, p <.01$.

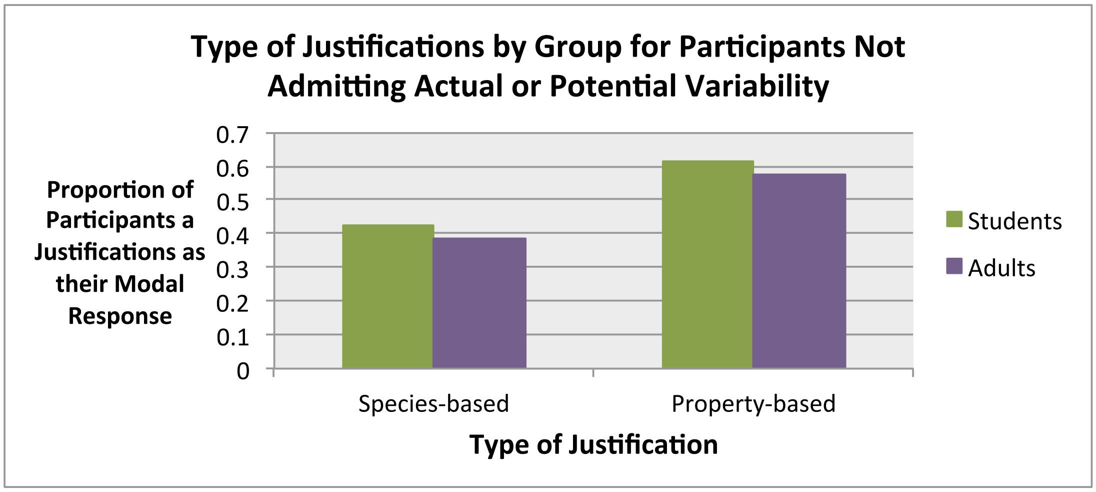


Figure 4.6. Proportion of participants in each group who provided (a) mostly species-based justifications or (b) mostly property-based justifications

This pattern in the proportion of modal justification type provided by Nahua participants supports the idea that the lower recognition of actual variability across properties -when compared to adults with a sound understanding of biological evolution- may be due mostly to relational/ecological thinking and not necessarily to essentializing a whole taxon. Engaging in this type of ecological/relational reasoning requires deep knowledge of relationships among organisms and their environments. The lack of significant differences -as hypothesized- between adults and students may indicate that Nahua students may develop early ecological expertise, thus exhibiting patterns of reasoning that are very similar to those of adults by the time they start middle school.

Regarding hypothesis 2, the results from the two ANOVAs supported the prediction that both adults and children would be likely to reject potential variability for internal and external species-specific properties, and in turn, would be more likely to admit potential variability for behavioral species-specific properties. There was no significant difference in the patterns of reasoning of adults and students, since there was no significant age group effect for the domain x property interaction for either group (for behavioral, internal, and external animal properties $F(2,156) = 0.4$, $p = .67$, $\eta^2_p = .005$, or for internal and external properties of animals vs. plants $F(1,78) = 0.07$, $p = .79$, $\eta^2_p = .001$). Additionally, as predicted, there was a significant property effect, with a fairly large effect size (animal properties $F(2,156) = 57.33$, $p < 0.001$, $\eta^2_p = .005$; plant vs. animal properties $F(1,78) = 41.91$, $p < 0.001$, $\eta^2_p = .42$). Post-hoc analysis revealed that as predicted, both adults and students were more likely to admit potential variability for behavioral properties rather than for external and internal properties of animals ($p < 0.001$), and more likely to admit potential variability for external than for internal properties for animals and plants ($p < 0.001$) (Fig. 4.7).

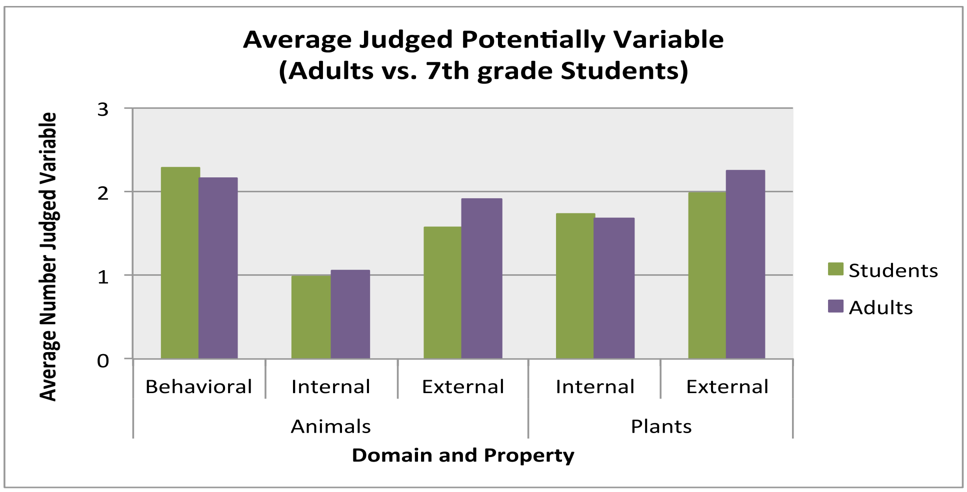


Figure 4.7. The average number of behavioral, external, and internal properties (out of 3) judged potentially variable by each group of participants.

The results for internal and external properties are similar to those obtained by Sousa, Atran & Medin (2002) and by Atran, et. al. (2003) for Brazilian and Maya Yukatek children, respectively, suggesting a cross-cultural innate causal potential that largely determines anatomical and physical properties for animals. However, in those studies behavioral properties were treated by participants the same as physical properties, while in this and Shtulman & Schulz' (2008) study participants were more likely to admit potential variability for behavioral properties. This may be due to participants' better knowledge of animal behavior or to a belief that changes in animal behavior are less likely to deter the survival of a single individual. Also, these results mirror those found for the responses for actual variability, that in conjunction with the types of justifications offered by Nahua adults and children, reinforce the idea that when faced with this type of interview Nahua participants tend to rely more on an ecological/relational type of reasoning rather than on essentializing the whole taxon (species) based on homogeneity of properties across individuals of a single species.

Lastly, regarding hypothesis 3, the prediction that both adults and students would recognize variability of external and internal properties significantly more often in plants than in animals was confirmed. The effect of domain was significant and the size effect was fairly large ($F(1,78) = 44.63$, $p < .001$, $\eta^2_p = .364$); similarly, the interaction between domain (animal vs. plant) and property was statistically significant despite the small effect size ($F(1,78) = 4.95$, $p < .005$, $\eta^2_p = .06$). Both adults and students judged plant properties actually variable and potentially variable more often than animal properties (See Fig. 4.6 and 4.7). In fact, adults and children treated the external properties of plants similar to the way they treated behavioral properties of animals. Because children and adults tend to have a better understanding of animal behavior than animal anatomy, these results suggest that the increased acceptance of variability in plant external properties may be also due to a good understanding of plant biology. Nahua people not only have expertise in breeding different varieties of corn, pumpkin, and beans that better survive in different agroecosystems, but they also learn from an early age to differentiate between different varieties of medicinal plants used in everyday traditional medicine. These culturally based practices may lead the development of an increased awareness of within-species variability, especially for those plants that are common in the Nahua diet and Nahua traditional medicine, thus reducing the essentialist bias. Because prior studies of this kind (e.g. Shtulman & Schulz, 2008) did not include plants, further research is needed to better explain the tendency of Nahua people to admit within-species variability in plants. For example, a task similar to the one presented in this study, but including common medicinal plants and unfamiliar plants, could be employed to test the hypothesis that ecological expertise and plant knowledge lead to a reduction in the essentialist bias.

4.2.2.1. Contextualization Principles based on the Results of the Essentialism Interview

The results of the essentialism study support my conclusion that the tendency of Nahua students to engage in ecological/relational reasoning facilitates the recognition of within-species diversity, but it may be that this relationship is valid specifically for organisms that are part of agroecosystems students are familiar with. Also, the internal properties of plants and animals proved to be the ones for which participants admitted variability the least, perhaps due to limited knowledge about the internal anatomy of plants and animals. Based on these results, I developed two principles to include in the science unit:

- Principle 3: Using students' culturally based knowledge of the variability of traits in local plants as a context to understand how external properties are linked to internal properties (relationship phenotype - genotype). With this principle, I aimed to use Nahua traditional knowledge about variability of external properties of plants and animals (phenotype) to facilitate the introduction of Western science ideas such as genotype, genetic diversity, and genetic pool. One example of how this principle was included in the unit, was modifying an activity which objective was that students were able to identify traits in organisms that have more than one variation, based on pictures of different snails, guppies, and orchids. Relying only on pictures of unfamiliar organisms to assess within-species variability seemed to have limited potential to engage students in focusing on discrete variations in traits. Therefore, this activity was modified to include different organisms that show great within-species variability and are very familiar to Nahua students, these were: corn, dogs, and pigs (Fig. 4.8).

Figure 4.8. Left: Example of organism (snails) used to address within-species variation in the original version of the IQWST unit. Right: a new image portraying phenotypical diversity in local varieties of corn.

This adaptation was intended for students to not only rely on pictures but to use their knowledge of those species to brainstorm and create extended lists of traits they have observed to vary in those species. This activity was followed by a teacher led class discussion where students were prompted to connect the idea of variability in traits within a population with the idea that alleles represent the instructions for variations of a trait. By engaging in this activity students can take advantage of their traditional knowledge to become engaged in thinking about genetic diversity. The link between traditional knowledge about biological diversity and the Western science ideas of "genes" is important because genes are internal entities with which students have limited direct experience, and teaching this concept without connecting it to the idea of phenotypic diversity may lead to reinforcing potential essentialist biases. For example, it has been reported in the literature that children and lay adults construe genes as properties that are causally responsible for observable properties that are common to all members of a species (Gelman, 2003; Wilkins, 2013). Introducing the idea of genes to explain the phenotypic diversity students are familiar with may be a fruitful strategy to avoid biological essentialism. This approach was used in other points of the unit allowing students to take advantage of their preference for ecological/relational thinking to comprehend complex Western science ideas that require recognition of changes in within-species variability, such as within-species genetic variability, population change, and natural selection.

4.3. Contextualization Principles based on Nahua Cultural Norms, Narratives about the Natural World, and their Experiences in the Public Education System

To better understand the meaning and relevance of the results derived from the teleology and essentialism studies, and to have additional sources of information to contextualize the IQWST unit to be relevant for Nahua students, data was collected from interviews with leaders of the community who are knowledgeable about Nahua traditions, middle school science teachers, and students, as well as field notes from ethnographic observations of daily activities in the community and the school. These data were qualitatively analyzed to identify common patterns that could further illuminate how Nahua people think about the natural world (for details on the analysis see Chapter 4). From these sources it was also possible to identify patterns regarding Nahua cultural norms that favor learning, and experienced of adults and youth in the public educational system. The patterns I found throughout this analysis were further confirmed, and sometimes disconfirmed, using two extensive ethnographies written about the Nahuas of this specific area of Veracruz (Rodríguez López & Hasler, 2000, Ornelas, 1995; Gómez Lara 2012).

4.3.1. Contextualization Principles based on Nahua Narratives about the Natural World

The Nahua people of Tequila lead lives that rely on the use natural resources for subsistence. They grow crops for their own consumption but not for commercial profit. Similarly, and they have animals such as chicken, pigs and sheep in their backyards or small areas of land adjacent to their homes. They also have communal lands (ejidos) covered by oak and pine forests that supply wood (Rodríguez López & Hasler, 2000). Nahua people in Tequila therefore have a close relationship with the natural resources in their environment that they see as bidirectional; that is, the Earth provides them with the resources to meet their needs and they take good care of animals, plants, and give offerings of gratitude to the Earth. This view implies a strong teleological view of natural kinds; however, this is not a teleological view where natural kinds are seen as agentic (e.g. "the dog is barking to communicate something to other dogs) but one in which natural kinds are seen in relationship to human needs and activities (e.g. "the dog is barking to protect our home"). This pattern of thinking was reported by most of the adult and student participants who were interviewed, and constitutes the most robust category in the qualitative analysis of ethnographic sources (Table 4.1). Participants described consistently during the interviews the different ways in which animals, plants, and non-living natural kinds serve a purpose for human needs. As I could observe myself during five months living in this community, every time someone experienced physical discomfort or felt ill, the first reaction of those around was offering to prepare an infusion of a plant that would specifically cure that symptom, or looking for someone more knowledgeable to know what plant to use. When the symptom was persistent or seemed to be an emotional ailment, the almost prevalent advice was to go see a healer of the community.

Table 4.1. Culture-based narratives involving animals and plants that explain aspects of life to which Nahua people have traditionally granted importance.

Category	Number of Data Sources*	References**
Animals deliver messages to humans	3	12
Animals, Plants, NLNK serve a purpose for human activities or needs	3	29
Cold and Hot foods and health	2	3
CORN is central in the Nahua diet	3	4
Traditional medicine: plants and animals serve for healing	3	15
Limpias heal from negative emotions	3	5
Animals, plants, NLNK should be protected	2	5
Holistic thinking	3	3
Magical animals and Nahuales	3	12
NLNK are alive	1	2
Offerings to NLNK	3	5

* This analysis is based on four data sources: 1) six interviews with wise women and men, 2) two focus groups with students, 3) two focus groups with science teachers, and 4) field notes from ethnographic observation conducted by myself during a 5 weeks living in this community prior to the contextualization and implementation of the unit.
** References mean the total frequency of a given code across data sources.

Using plants and animals for healing is a dominant narrative in the Nahua community of Tequila, as observed in Table 4.1, which provides the frequency of references in this category ("Traditional medicine: plants and animals serve for healing"). For example, 7th grade students demonstrated themselves as knowledgeable about plants during the focus groups, regardless of whether they were Nahuatl speakers or not, as it can be seen in the following excerpts:

Focus group with bilingual students (Nahuatl/Spanish)

Gabriel: the aloe is an important plant
Interviewer: Aloe?
G: because it is used for many curative purposes, like when someone falls and is bruised then it is just cut –the plant- and you put it on you this way or you cut a stripe, warm it up and put it on you.
I: and it heals…

G: and it heals, and if not, then there are many plants, they are used even for illnesses, for many things
Sandra: for avoiding hair loss

Focus group with monolingual students (Spanish)

Interviewer: very well, let's talk about plants now. What plants are important in your community?
Josie: the medicinal ones
I: ok Josie, which ones are the medicinal ones?
J: well, from long time ago in rural communities plants have been used to relief different ailments or illnesses, or to control them. Here in Tequila medicinal plants continue to be used, for example the bougainvillea, the lemon leaves, the avocado leaves…
I: Bibiana here says rue and avocado
Ronald: chamomile
I: Alma, what did you say?
A: "tapón"
Kyle: rosemary, and many more
R: Bull's tongue (common name of the plant)
I: so do you know a lot about plants?
(all participants giggle)
I: who taught you about all those plants?
K: My grandmother
A: My grandmother
[the rest of the participants agree]

These excerpts provide evidence that students have familiarity with plants and how they see them as instruments for human wellbeing from an early age. This idea was also highlighted by wise men and women of the community, as shown in the following excerpt from the interview with Chela is representative of the ideas shared by other adults who were interviewed:

Chela: Well, in general all the greens are taken care of, not sure if there is a special one… well all of them, including cactuses and fruits like maguey and the flower of maguey, all that is edible, but those healing plants, there are some that need to be carefully handled because they may have psychotropic effects and they know them, children know them, and there are plants occupied for "limpias" and they also know those and they say this is not for eating

and this is for healing like the elderberry, or the rue, for the "limpia" righ? This way you remove stuff with the egg and that's it, for the bad vibes. If this is for curing indigestion you use other plants, for example "asiomate" for comforting, people say it need to be set on fire with alcohol, you have to set it on fire quickly and put it on a cloth, you extinguish and put it on you and it feels very good, this little plant is called asiomate. If this is for when you have a fever, you also put that plant on the soles of your feet or your belly, or also there is a tall tree called "ilite", it is a cold plant, so for taking the heat out people use the "ilite" and other tender shoots, they are called "cogollitos", shoots of peach or cherry, whatever they find that is fresh, the leaves of the "ilite" and a large leave called "higuerilla", all that and alcohol and they put it on you, and if it is for indigestion also the "higuerilla", do you know the "higuerilla"?
Interviewer: yes
Chela: well, there is white and red higuerilla, for boy and for girl, they do not use the same one; that leave is the same if the child is coughing or has asthma, they put the roasted higerilla, if it is for indigestion they put lard and ashes on the leave and put it on your belly, the leave, once it is burned they remove it.

The above excerpts are examples of references that were grouped in the category "Traditional medicine: plants and animals serve for healing", that belongs to the meta-category "Animals, Plants, and NLNKs serve a purpose for human activities or needs". This data confirms what has been described by the two main ethnographers of this region, that medicinal plants and healing practices are central in this community and that people start developing knowledge about using a wide variety of plants from childhood (Rodríguez López & Hasler, 2000; Rodríguez López, 2003). This emphasis in seeing natural kinds as instruments for human wellbeing is reflected not only in students' and adults' descriptions of using plants for traditional medicine and for their main diet, but also in their legends and spiritual beliefs. Participants spoke of animals especially, both as living things that contribute to human activities such as agriculture or healing and also as deliverers of messages. On many occasions there was mention of Nahuales (a human with the ability to transform her/himself into one specific kind of animal when needed). The frequently mentioned stories of Nahuales (see Table 4.1) are of special interest because they suggest that Nahua people may see some continuity between animals and humans, and that there is an idea that organisms are able to undergo radical transformations in response to the challenges of the environment. Such stories of animal-human continuity belong to the Nahua legends that have been orally transmitted for generations, despite being judged as "ignorant" by the Mexican majority population (Gómez Lara, 2008). Evidence of the importance of these stories is that most interviewed participants spontaneously mentioned Nahuales when asked "are there stories about animals or plants in your community?" The sentiment of those stories is one that connects humans to animals in an intimate way, reinforcing an idea of interdependence as we can interpret from Alma's words, a 7th grade monolingual student:

> *Alma: I was told that the ancestors killed animals, therefore Mother Nature gave each human being a nahual so there was no more animal killings, I mean an animal that, I don't know, like if the animal gets hurt then one is hurting oneself, because it feels it then we can feel it if the animal gets hurt, we can feel it.*

These stories are orally transmitted, especially from grandparents to grandchildren. Grandparents have a special role in the education of children in this community. They are trusted sources of knowledge and create strong bonds with children and youth. In the focus group with bilingual (Nahuatl-Spanish) student they described how they have learned different stories from their elder, including stories about nahuales:

> *Maria: for example mi grandpa tells, when my grandpa is conversing he spills it all out (giggles)*
> *Interviewer: spills it all out? To everyone around?*
> *M: uhuh, for example, he has told me stories about the first time when water pipes were placed along the road where I live, like that, many stories*
> *I: did you want to say something Sandra?*
> *Sandra: likewise, mi parents have sometimes told me how they built the house where we live and how they built the road*
> *I: do they tell you stories about animals or plants?*
> *Gabriel: yes, we are told stories about animals and plants*

I: do you remember any?
G: one said that… oh, I just forgot
I: Alfredo, did you want to share something?
Alfredo: one about animals, about wolves. It is said that there were some wolves before, and it is said that they used to chase chicken, even when the dogs were around they kept on chasing the chicken, so people chased one wolf away, far far away, and it appears that while passing by a house the wolf got directly inside and started turning into a lady.
I: Have others heard this story?
(all six participants nod).

All wise men and women mentioned stories about animals delivering messages or warnings to humans, and stories about nahuales, thus confirming the importance of this narrative in the Nuahua community. For example, Augusto, a wise man of the community who used to teach Nahuatl at a local university and now owns and runs a small diner, shared during his in-depth interview:

Augusto: according to what I have told you it can be concluded that there is a relationship between the magical, the good and the negative, that can broadly lead to that specific classification of animals, birds, cats, mmm the spotted cat, the opossum, mmm the squirrel. Then, it is indeed believed that they have a function of this sort, because additionally, in the Nahua world there is a belief right? That there are people with certain faculties, right? of turning into animals, those are the famous nahuales. The nahualismo exists in the pre-hispanic world, and obviously the magical aspect is there, but obviously not every person can be one (a nahual).
Interviewer: what does that person need to have?
A: no, be born, be born, be born with that quality of having her nahual and her nahual is an animal precisely, and obviously there is this idea that is subjacent to this story, that is not widely known, but that exist in this belief, that there is magic in the animals, right? and in human beings, so there are nahuales.
I: how does this work? When a person has her nahual, can she transform? Or how does it exactly work? For example, can a person pass on her nahual to her children or isn't that the case?
A: no, no. The person is born with that faculty and that's it, the magical faculty that person has is to be able to transform in that animal when she wants to. What it is known is that that animal can cause damage or can be beneficial, that is what it is known. Now, how can it be transformed into an animal, well, it depends on every nahual, right? One of the most common stories is that the person with that faculty, generally at crossroads, where a trail meets another to form a cross, the person goes there and perhaps through a series of invocations, right? At that point she can transform into a nahual but how it happens may

vary and it is not really known.

From the interviews, focal groups, and field notes, I could conclude that the Nahua people see themselves as closely linked to animals because of the services they provide for human wellbeing, and for the sense of spiritual connectedness among animals, plants, and humans that shapes the Nahua worldview. According to Rodríguez López (2003), this connectedness is part of the Nahua system of beliefs in which when born, every person is linked to an existing animal. Even when people do not know which animal they are linked to (their nahual), they assume that any harm to that animal will result in harm to their own physical integrity, thus creating a motivation to take care of all animals around them. These descriptions in Rodríguez López ethnography confirm the interpretation that the stories about Nahuales are central to this community, and it adds onto it that these stories are powerful enough to have been orally passed on since before European colonization.

4.3.1.1. Contextualization Principles based on the Results of the Nahua Views of the Natural World

The above described narratives, from a teleological view of animals and plants to a flexible understanding of continuity between different species, may suggest a potential conflict with Western science ideas such as natural selection, that requires individuals to understand species as distinct categories with within-variability, and subject to change at the level of the population but not at the level of the individual. However, I see these narratives and worldviews as resources that can motivate students to become engaged in understanding how other cultures have developed different ways of explaining the natural world (Aikenhead, 2001a; Bang & Medin, 2010). Further, the narrative content can also serve to bridge the border between the culture of Western science and the Nahua culture, facilitating the learning of science in ways that value students' culture

(Aikenhead, 2001b). Within this framework, the following two contextualization principles are based on the idea that Western science concepts and practices presented in the IQWST biology unit can become a context. That is, a situated manner of teaching and learning science where Western science “is expanded to value the multiple communities in which students participate and the resources, roles and expertise that come along with those communities” (Tan & Calabrese Barton, 2010 p. 316). In the case of the present study, the following principles will use the students’ deep knowledge that students have about plants and animals, as well as their traditional oral narratives as resources for learning Western science, while highlighting the expertise and value that comes from their own communities.

Principle 4: Using traditional knowledge of medicinal plants as a context to explore Western science concepts and to engage adult members of the community in the classroom.

Because using plants to heal is a central practice of this Nahua community around which children and adults develop a vast knowledge of plant biodiversity, this practice was included in the unit as a core topic that was revisited several times in the unit. From the interviews and my field notes, I learned that it is common to hear people saying that healing is a gift that runs in families, but also one that requires also interest from those who want to learn. This narrative seemed promising for studying healing as a “trait” in the Western science sense, opening opportunities for students to engage in learning about what traits are, whether a trait is inherited or acquired, etc. Also, incorporating the narrative of healing into the unit aimed to facilitate involvement of respected elders into the classroom and student-family exchanges about the science classes at home. An example of how this principle was operationalized into the curriculum is presented below:

Nombre ____________ Fecha ____________

Let's Reflect 1.1 The Gift of Healing: Acquired or Inherited Trait?

Doña Izel Tzanahua is 65 years old and she is a beloved and respected member of her community because she has healed countless people. Doña Izel knows medicinal plants since she can remember. She recalls being a little girl and running into the forest looking for herbs to bring to her grandmother to make remedies. As you can imagine, Doña Izel's grandmother also healed people. In the Tzanahua family it is said that healing is a special gift, but not everyone has it. For example, among Doña Izel's seven children, only Porfirio know how to cure using medicinal plants.

Porfirio claims that he inherited the gift of healing from his mother and grandmother. However, one of his sisters disagrees y thinks that he can heal others just because he was interested in learning. Would you like to help Porfirio and his sister resolver their disagreement?

Do you know someone in your community that agrees with Porfirio that the gift of healing is inherited?

1. Do you know someone in your community that agrees with Porfirio that the gift of healing is inherited?

   YES ☐ NO ☐

2. Which reasoning led these members of your community to think that the gift of healing is inherited?

____

____

3. Do you know someone in your community that agrees with Porfirio's sister that the gift of healing is learned?

   YES ☐ NO ☐

4. Which reasoning led these members of your community to think that the gift of healing is learned?

____

____

____

5. Fill out the following comparative chart with the reasons why each type of explanation can be useful for people to understand why some people can heal others.

Healing is Inherited	Healing is Learned

Keep this case in mind. You will have a couple of classes to discuss this topic with your family, friends, and after reading 1.3 (about athletic performance) you will use all what you have learned to help Porfirio and his sister to settle their disagreement.

This was one of the introductory activities of the whole unit, after which students started learning about different human traits and its variations, how to represent those variations in bar graphs, and learning more about some traits, like athletic performance that are a combination of inherited elements (genes) and environmental factors (training). While doing this, students had to interview members of their families and communities, to gather information about the reasoning people provided when agreeing with Porfirio (healing is inherited) or Porfirio's sister (healing is learned). Starting the unit in this way helped frame the unit with a Nahua practice that is powerful and well known by students and motivated them to learn about how scientist would explain this phenomenon and how it is explained in their community. This is the first instance where the idea of having different explanations for a phenomenon is included. In this case, students are looking for reasons that people in their community provide to endorse each position, getting familiar with the idea that it is acceptable to have co-existing perspectives, which can be supported by different reasoning that can be functional in different contexts. This first time students did this exercise within their own cultural context, and after having learned about traits, DNA, and genetics, they were presented again with this case:

Nombre Fecha

Let’s Reflect 1.2
The Gift of Healing: Science and my Community

At this point, you have already discussed the story of Doña Izel with your family and friends. You have also learned what scientists think about inherited and acquired traits. Now is the moment to reach a conclusion.

Answer the following questions with your team:

1. How are the traits of athletic performance and healing similar?

____

____

2. How are they different?

____

____

3. How are similar or different the explanations of your family and those of scientists that you learned in reading 1.3?

____

____

A special guest in our class

To learn more about people who can heal others, prepare two questions you would like to ask to a community member who knows how to heal others, since she is visiting our class.

____

____

Whole Class Discussion
What is my stance regarding the gift of healing? Is it inherited or acquired? Why?

This activity is built to engage adults of the community in the classroom. It also introduces the idea of having different explanations arising from the Nahua culture and from the Western science culture, which sometimes overlap and sometimes are different. Directions were provided to the teachers so that they could lead the whole class discussion in the spirit of "we all do not have to agree on everything yet, but we need to understand how we think in our community and how scientists think so we can decide when and how to use each kind of reasoning". This allowed students to become familiar with the idea of crossing borders between narratives tied to their ethnic identities that they are familiar with and new ways to explain the world coming from Western science. By design each student is left to decide and justify what is his/her stance according to the information gathered and the discussions with others, providing an opportunity to practice agency. Opportunities to practice agency are important for ethnic minority students practice agency, so that they develop a sense of empowerment that allows them to question the hegemony of some forms of knowledge and the delegitimation of their traditional knowledge. This then facilitates their own navigation of multiple ways of knowing. According to Bang, Medin & Cajete (2009), supporting students to navigate multiple ways of knowing is a core characteristic of effective science learning environments for all students, including indigenous children. To further support students in border crossing between their traditional forms of knowledge and those of Western science, an additional principle was created to incorporate traditional Nahua narratives into the unit.

Principle 5: Incorporating traditional Nahua oral narratives to legitimize students' traditional knowledge in the context of the science classroom, thus facilitating border crossing into Western science. Oral narratives were mentioned consistently by adults and students in this study (see Table 4.1) and are also described in the ethnographies by Rodríguez López and Hasler. These narratives were included in the unit as an opportunity for students to practice border crossing between powerful narratives they are familiar with and complex science concepts such as population change. These instances of border crossing were scaffolded with the incorporation of comparative charts that facilitate students' visualization of coexisting views of the world with their corresponding reasoning, and opportunities for them to decide in which contexts they would use each. The following is an example of how this principle was operationalized in the unit:

Nombre Fecha

Let's Reflect 10.1 The Nahuales

So far you have learned about inherited traits, variation, and population change. As you learned, all individuals in a population have variations. In other words, they are not completely the same. But what would you say if you see a dog that is very different to other dogs you usually see in your community? The Nahua culture has stories to explain these events and the science culture has different ways to explain those same situations. In this class we will analyze the two ways of seeing this situation of the different dog.

Story about Nahuales[1] (also in video)
One day in the afternoon uncle Luis told me stories about nahuales. Nahuales are people that can transform into animals like pigs, donkeys or chicken. They do that to steal other animals. My uncle said that one night a grandpa was passing by a house close to his and he saw a dog, about 80 cm tall, coming from that house. He was so scared that he even had goose bumps. He got so scared of that big dog that he could not even move. He became paralyzed for a while. When he got calmer he went home and told what happened to his family.

The next day my uncle left for work in the early morning, he was a construction worker. Coming back he saw the dog again, but now the dog was leading a donkey loaded with sacs of corn, so many that the poor donkey was almost falling apart. My uncle was so surprised that he could not believe what he was seeing. Days went by and my uncle was so afraid of running into that huge dog again that he was carrying a gun in case he needed to defend himself from the dog. One day, my uncle was coming back from work as usual and he run into the dog at his home, to his disbelief, the dog was taking away my uncle's donkey loaded with corn. Without much thinking he beat the dog as hard as he could until the hurting dog suddenly talk and shouted: "stop beating me!" while escaping into the dark. The next day all neighbors knew that Don Simon, my uncle's compadre, woke up all beaten. When hearing this my uncle said worryingly "oh my compadre! I beat him without knowing he was a nahual." All this happened, according to my uncle Luis, in Cuahuimastlac San Francisco, in the State of Tlaxcala.

Have you heard this story before? Ask your family and neighbors if they know this story and why they think it is important in the Nahua culture.

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[1] http://geromeronte.blogspot.com/2007/07/los-nahuales.html

Why do you think this story has been passed on generation after generation in the Nahua culture?

____

____

Use your science knowledge to answer this question: What can be the reason that you find a dog with a different phenotype from other dogs?

____

____

Whole class discussion aided by your teacher: what are the differences between the Nahua stories or legends and the current science knowledge?

Nahua Stories or Legends	**Current Science Knowledge**

In which places and moments would you use each type of explanation? Why?

	Places and moment you would use this explanation	**Why?**
Explanation of the Nahua Oral Tradition		
Explanation from today's scientists		

Examples similar to the one provided above were introduced throughout the unit, making visible the local narratives with which students connect and giving them the same status as Western science. The charts in these examples constitute a scaffold to help students make sense of the differences and similarities between different ways of explaining the world; and once again, place each student in an agentic position where she or he has the possibility of mastering the two ways of knowing and deciding when and how to use each view. This principle is closely related to Culturally Relevant Pedagogy (Ladson-Billings, 1995, 2006; Ladson-Billings, 1995; Pewewardy, 2003) in the sense of students developing cultural competence in their own culture while succeeding academically in the school subjects.

4.3.2. Contextualization Principles based on Nahua Narratives and Experiences with Public Science Education

One of the most salient experiences of the Nahua people in Mexico is ethnic discrimination. Indigenous students in Mexico experience intense discrimination in the public educational system, especially after elementary school (1st – 6th grade). Elementary schools serving indigenous communities tend to be located in the students' communities, and the instruction is bilingual (indigenous language of the community and Spanish). However, only the elementary level offers bilingual instruction, after which all instruction is in Spanish. To receive education in public schools, especially after the elementary grades, students have to cease using their home language and wearing their traditional garments. On occasion they have to travel several hours to attend school or alternatively live with extended family with homes closer to a school or live in boarding schools (Carnoy et al., 2003). This reality is also faced by the students who participated in the present study. About 80% of the students in the middle school (secundaria) in Tequila come from bilingual elementary schools where they had bilingual teachers who lived and participated in their communities. This experience drastically changes when they start middle school at the technical secundaria of Tequila, where none of the teachers speak Nahuatl, and among the 30 teachers only one lives in the community. There students must also conform with a strict uniform policy, and while some students living in the center of the municipality need about 20 minutes to arrive at school, other students have to travel two hours by bus everyday, or walk for more than 1 hour.

This situation is an improvement compared to the conditions ten years ago, when there was no middle school in the municipality and the access to education beyond elementary school was difficult for indigenous students in this area. Despite recent improvements, indigenous students in Tequila continue experiencing a stark contrast between elementary education where they are in a context that is protective of their traditions, and secondary education where they face intense pressures of assimilation into the Mexican majority culture. In fact, overt discrimination in middle school is one of the most prevalent themes found in the interviews, focus groups, and field notes focused on adults sharing their experiences with public education (Table 4.2). Interestingly, none of the students mentioned discrimination or provided examples of discrimination. This may be due to the fact that they were in their first year of secondary education and they are more concerned with making sense of a decontextualized education, as I will illustrate with their own words in the following paragraphs.

Table 4.2. Experiences and perceptions of the community about the science education provided in public schools (categories with more than 10 references shown in bold print)

Category	**Number of Data Sources**	**References**
Access to careers in science to serve the community	3	6
Attrition	4	7
Children reject TIK and practices	3	3
Confusion between TIK and WSK	2	7
Decontextualized education	**4**	**12**
Difficulty to relate to teachers coming from cities not speakers of Nahuatl	3	6
Empowering students and people	3	3
Learning science could help students value the resources of their communities	2	2
Limited access to careers in science	3	7
Overt discrimination	**3**	**25**
Pedagogical training is low for teachers working in indigenous schools	**2**	**12**
Scarce resources for teaching in indigenous schools	2	7
Teachers in elementaries of indigenous areas help reduce the	2	4

discrimination experienced by students and increase their motivation to learn		
TIK is not taught and getting lost	**3**	**14**
TIK is not valued (WSK is the truth)	**4**	**12**
WSK should be complementary to TIK	**2**	**11**
Suggested Strategies		
Developing pride of the Nahua culture	3	6
Learn through conversations (platicar)	2	5
Learn through experimentation (first hand)	2	4
Teachers who become mentors	2	2
Using technology (videos)	2	2
Ways in which the Nahua culture explains natural phenomena that are similar to the culture of Western science		
Building knowledge through observation and experimentation	**2**	**10**
Ecological knowledge	3	12
Knowledge is distributed in the community and shared	3	4

Regarding discrimination experienced within the public education system, all interviewed wise men and women spontaneously described this similar experience. Daniel, for example, a former chemistry professor at a state university described how he had to leave his hometown very early in life to access education and how he was discriminated against by his mestizo peers and teachers in the process. The following quote is representative of how he makes sense of that experience in retrospective:

> *I think it would have been different having had the opportunity to complete high school here. I mean, now that I reflect and that I am more aware of what the Nahua culture is I think that we could have done more, right? We could have had more, if having grown and matured within the culture, we would have a different type of consciousness and intellectuality. For me, the Nahua culture is very rich, extremely rich, and it is getting lost due to the fact that we keep on suffering this discrimination at urban areas, discrimination from the government and from all institutions, it is a very unfair and not balanced treatment.*

For Daniel, this experience of feeling discriminated in public educational institutions was prevalent, even as one of the few indigenous individuals of his generation to become a science professor at a public university. About this period of his life, he shared:

> *When I was a professor at the university I used to tell people I am indigenous and people laughed, other professors laughed about me. And I always defended the need for students to go to the field and get to know indigenous communities, but to them this was contrary to the capitalist development, and the supposedly scientific development.*

To better contextualize this quote, it is important to know that Daniel is light skinned and his use of Spanish does not reveal that he is a Nahuatl speaker. Therefore, given his role as a professor, his colleagues laughed when he identified as indigenous because to them those traits (skin shade, use of language, etc.) did not align with that role. They interpreted Daniel's statement that he is Nahua as his being eccentric or funny. Even today, now that he is retired and has returned to his community after decades in the city, he is considered "eccentric" for doing so. Daniel's experiences speak to the fact that it is not only difficult to access education and succeed academically if one is indigenous descent, but when one has access, this often means facing social pressures to give up the indigenous identity. Unfortunately, these experiences continue to be common today as Chela described:

> *There are now bilingual elementary schools where if teachers are Nahuatl speakers, then their classes are taught in Nahuatl and a little bit in Spanish, but not completely in Nahuatl because it has been getting lost with time, but they make the effort that children do not lose their language, so I can speak Nahuatl then I explain everything in Nahuatl to the students, but in the other system, the National public one, they do not speak Nahuatl. Teachers are not Nahuatl speakers, and those who are do not use the language because it is not expected in the public system. For example, there is a nearby community called Santa Cruz and they have a public elementary where teachers do not have to speak Nahuatl to children, even when some teachers are from here, from Tequila, they won't speak Nahuatl to children. And a little girl, the granddaughter of the artisan lady, I met her and her sister when they were seven or eight years old, always dressed in traditional attire, beautiful little girls, and their mother told me that they were not attending school anymore. I asked why, and you know, they told me that they do not want to go to school because at school they do not want them*

to go wearing their traditional clothes, but the girls do not want to stop wearing their clothes, they do not want to use an uniform, so they prefer not to go to school. So I thought, this is really bad, that because the girls want to defend their identity they can't go to school.

This type of discrimination against Nahua traditional clothing, language, and identity is deeply ingrained and normalized in the public educational system. Genaro, a wise man of the community who started as a bilingual elementary teacher but has been working as a principal of middle schools in indigenous areas for the last ten years, described how he has unsuccessfully attempted to change rules that undermine the Nahua identity:

> *<u>Genaro</u>: I wondered why couldn't they continue using their traditional attire when it is so beautiful and full of symbolism, but the authorities said, "No, they have to use the uniform because that is the official attire." I argued, I sent an official letter, until I was finally relocated to a different school, and that is how I arrived to the school in Tequila.*
>
> *<u>Interviewer</u>: so, did they choose a new principal willing to impose the uniform?*
>
> *<u>Genaro</u>: exactly, and so they did. But that is not the worst; the worst is that children now believe that they are going to be better because they are using the uniform. That is truly sad.*

As illustrated by Chela and Genaro, even today students are discriminated in public institutions because of the way they dress and talk. Similar experiences of discrimination have been reported by Carnoy et. al. (2003) who maintains that discrimination is one of the most important factors that explains the limited and difficult access of indigenous students to post secondary education. Part of this engrained discrimination is the fact that indigenous students are held to lower expectations and deficit views by their teachers. Teachers in indigenous middle schools have internalized narratives where students' culture and language are seen as barriers to learning, as it can be seen in the following quote from Antonio, one of the science teachers in the middle school of Tequila:

The language [Nahuatl] does not allow the child to have a better [sic] intellectual development, which causes elementary teachers to fall behind because they have to make an extra effort to give or transmit knowledge to students. So they [the teachers] only focus on teaching them [the students] how to write or read. They [teachers] fall behind in science programs because it is not important, in their opinion. Therefore, children come to middle school lacking information or prior knowledge, so we have to teach them topics they should have learned in elementary school.

These deficit perspective where indigenous students' are seen as blank slates that arrive at middle school with no knowledge and a "problematic" language that interferes with learning, has been reported to be a commonly held idea among teachers, leading to high levels of repetition, reprobation, and attrition for indigenous students (Ornelas, 1995). The result of this pattern is that the levels of illiteracy for indigenous communities are higher than those of the rest of the Mexican population. A further outcome is that their levels of completion of elementary and middle school continue to be lower than for any other Mexican group. Although important progress has been made in the area of providing educational infrastructure and access to education for indigenous communities, the dominant perspective has been one of "integrating indigenous people into modern ways of life", which has generated a lack of respect for traditional indigenous knowledge and traditions in the public school system (Ornelas, 1995). These views reinforce the discrimination indigenous students experience and lead to decontextualized curricula, which is also one common way of how indigenous students experience public education. It is therefore expected that discrimination is one of the most robust categories identified in adults' interviews (Table 4.2). The following excerpt from the conversation among science teachers is illustrative of the awareness of teachers about how decontextualized the national programs are for their students, but still they see themselves having limited tools to improve their instruction:

Alicia: I think that the topics covered in our books are not always contextualized, for example, there was an activity that asked students to draw a map indicating how many blocks they walked from home to school, and my students asked: "what blocks?" and I

thought, yes, what blocks? There are not blocks here but hills! Or sometimes the book says check this website for further information, but students do not have access to computers and if they go to a computer center they will have to pay to get online.
Antonio: like Alicia says, we need to follow a program that is probably not well designed for the two contexts, the urban and the rural ones, and that limits us greatly. With the current reform we are limited because many topics were removed, for example, we do not have environmental education anymore because, supposedly, it should be transversal to all subjects.
Alicia: one cannot really adapt the program.

The tension between National programs that are not contextualized for indigenous students and the efforts of teachers and principals' to determine how to best teach their indigenous students, is also reflected in the in-depth interview with Genaro, a wise man of the community and principal of a nearby community's middle school:

Genaro: There is no flexibility, there is rigidity even when they [the government] say that the teacher can implement, but they always end up saying that you have to follow the program, because we have supervision and revision, and they say [suvervisors] "why did you cover until this point only?" [now assuming the voice of the teacher] "Well, it is because I added this, and I changed that" [going back to his own voice] and no matter how many explanations or justifications you give them [the supervisors], they always dislike these changes, so the teacher prefers to strictly comply with what he is asked by the government. We are somehow dogmatic, or very dogmatic in this regard, so much of what is essential in the indigenous culture gets lost, because teachers could foster activities that would strengthen the indigenous culture, but they don't.
Interviewer: I noticed that children and youth are knowledgeable about different aspects of the Nahua culture, who do they learn this from? how do they learn this?
Genaro: from their parents, right? from their parents in general because at school the reinforcement of their ethnic identity does not occur 100% of the time. In fact, because our teachers are not bicultural or speak Nahuatl, there is a huge breach between the science teacher and the indigenous student from the very beginning, the teacher arrives and starts explaining chemistry for example, let's say chemistry, and he starts to talk about nomenclature of the elements and about this compound NHO3 with its valence and then he starts talking about a different compound. If you do not know how to explain what valence is to the indigenous student, he will just not understand. At that moment he will bring down the curtain and will start speaking in Nahuatl to his peers. Oh God! And that's it for that student. This is one of the most important problems we have right now because of ENLACE. ENLACE is a National external assessment applied to every student in the

country, but it does not take into account the differences in ethnicity, regional differences, different difficulties students may have.
Interviewer: you have also told me about different aspects of the Nahua culture, are those aspects different from what is taught at the science classes at public schools?
Genaro: yes yes, we come back to what I was telling you. There is a program, a national education program, copied from other countries such as Chile or Spain, the current one is copied from the Spanish program and it of course does not take into account most of those aspects [Nahua culture]. The program is standardized and it does not allow every kid to develop his own knowledge through the experiences he already has.

The seventh grade students I interviewed also communicated that they perceived a lack of contextualization in the science programs and instruction they experience. They reported how this confuses them and decreases their liking of the science class, as it can be seen in the following excerpt from one of the focus groups:

Gabriel: What we learn in the science class is almost opposite from what we say [Nahuas]. In our community we are told stories about symbolic plants and animals, at school we only learn how plants grow… and we can take it as something spiritual or something like that. We do not know anymore what is the real story.

Maria: we are taught about different places but not about the region, well, about Veracruz or whatever, but not about here, about Tequila.

Sandra: well, I don't know… I can barely understand the science class, how can I explain… is like if one day we are talking about an experiment that I do not understand, then I do not like it anymore, that's it. But let's suppose we talk about some plants or something like that, then I understand.

This last excerpt not only illustrates that students perceive their education as decontextualized, but that it also diminishes traditional knowledge central to adults in the community, as revealed by all wise men and women of the community (Table 4.2). The following quote from Maestro Santos, one of the wise men of the community who is the supervisor of the local indigenous elementary schools, aptly represents the ideas shared by other adult leaders of the community:

Children do not learn our traditional knowledge anymore. At school they receive sophisticated information, modern technology, but the teacher is not informed about our life, and that is the force of our lives. They do not know our culture, so it is getting lost. We should learn science because it is our force. I mean, I can speak Nahuatl, Spanish, and English, but what's that for if our environment is deteriorated, and we loose our rivers, caves, and mountains. There are many of those cases of destruction and it is painful…. Very few of our youth go to college and those who go choose majors in the humanities.

This loss of traditional knowledge and the lack of interest in science careers of youth in this community were explained by the adults as being a product of delegitimation of their Nahua knowledge in favor of Western science and mestizo views of the world held by the majority of the Mexican society (mestizos). This feeling of delegitimation of their own knowledge is accentuated in science classes and in spaces in which Western science is imposed as the only correct view, or as Carter (2003) describes it, when traditional knowledge is only valued for its perceived service to Western science goals (e.g. traditional knowledge of medicinal plants is valued when scientists are interested in "discovering" new substances with pharmaceutical potential). This sentiment is captured in the experiences shared by wise men and women, as well as students of the community.

Daniel (former chemist)

After having some debates with some gurus of scientific research [agronomists], I started to grow frustrated with their way of comparing things. It just could not be compared! The fields of Germany or Ohio with the Sierra of Zongolica! Then one day came a gringo researcher and he challenged us, to go to the Sierra and produce a hundred tons to see if it was true that it was so good [indigenous agricultural technologies]. Well, he was very critical of Zacatecan agriculture, because they [Zacatecans] could produce 400 kilos of beans or corn in a semi desert but no scientist could achieve the same, they did all sorts of experiments and they could not produce as much. But they [scientists] never acknowledged this, not in any publication, but in some conferences some of us began to make that evident [indigenous agricultural techniques] and also to maintain that science does not have all answers, that is not possible to exploit nature to the point of making it unproductive. So I realized that science has its limitations, in other words, that we could make progress but not with that sensations that we had to exceed the production of European countries or the United States.

Josie (7th grade student)

> *Here at school when we learn about animals in biology class we are taught about animals and we are only told where they live, their main characteristics. In contrast when we are taught at our homes about the diversity of animals living in this region, our grandparents tell us whether those animals bring good luck or bad luck, what they [ancestors] did with them [animals] before, whether they were seen as part of a sacred ritual or incarnation of a god, or stuff like that. And here at school they do not teach us that because it could be said that those ideas have been abandoned by our ancestors because many people do not believe those ideas are true.*

Despite the consensus among participants, that their traditional knowledge was considered to be of lower value than Western science, most participants provided examples or proposed alternative scenarios where traditional indigenous knowledge could coexist with Western science knowledge in a complementary way. They do not see traditional knowledge as irreconcilable with Western science, and all adults see the need for youth to learn Western science, but in a way that values traditional knowledge and that allows students to take pride in it.

Augusto (anthropologist and former Nahuatl instructor at a local university)

> *The scientific perspective should be important, right? the classification of plants and all that is a complement of what they [students] already know, and that is of course important, but it is complementary to what they already have, which is also a scientific knowledge although not recognized, but it has its foundations because you know well that the allopathic medicines we take come from herbs.*

Daniel (former chemist)

> *In the UVI [local indigenous university] I have been trying to converse with youth that already have the seed of traditional medicine so they focus in that area, right? It would be so cool because that way, the combination of scientific knowledge and traditional knowledge would be an interesting mix, but I have failed to convince the people [faculty and students].*

Chela (former nurse and owner of local diner)

> *What is taught at school comes already made and written by a foreign type of thought. If that could be complemented with the knowledge children bring and families could contribute to children's knowledge, a child would grow with a more integrated knowledge, it would be*

complementary because it would not privilege one side or the other but they would complement each other. In that case the knowledge, the local knowledge would be taken into account. What is prescribed would only complement and respect what a child already has, educating a child, not instructing her but educating her.

Alicia (science teacher at the middle school in Tequila)

What I like about this subject [science] is that they [students] already have the empirical knowledge, they already apply it to their lives. Ideas as simple as a seism, or when will rain, thunders, they already bring that knowledge. I just have to polish and differentiate what is empirical from what is scientific and reinforce the knowledge that they bring from home, so they gain a more meaningful knowledge, but they already know, because here in La Sierra they already know empirically right? And sometimes they [students] even master it. That would be my experience teaching science for four years here.

The interview excerpts highlight the intense desire among the adults for more culturally relevant pedagogies. This, however, is not considered by some teachers to be a suitable approach to science learning. For those teachers that see value in culturally relevant pedagogies professional development that provides them with tools to do so is unavailable[2]. In fact, part of the experiences communicated by the adult participants

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[2] The history of sending the least prepared teachers to indigenous communities is not new in Mexico. During the 1980s and 1990s pedagogical schools recruited students among low income communities with the prospect of a short program to receive a teaching degree (3 years only), a growing job market -thanks to the expanding coverage of the public system of education at the national level-, job security, benefits, and a strong union advocating for teachers' interests. During those decades the National government implemented measures to extend teacher preparation programs to four years, but those who had joined the systems after completing shorter programs remained in-service. On the other hand, alternative ways were used for science professionals to enter into the system and those remain valid today (professionals holding bachelors' degrees in engineering, math, or science can become teachers with no need of completing a teacher preparation program a priori). The effects the strong teachers' union has not been overall positive for the quality of education offered to indigenous students. Despite the fact that one of the union's principles is to contribute to the quality of education for all, the union has disempowered indigenous communities to check in and get involved in the functioning of the schools in their communities, because despite the prevalent teacher absenteeism and abandonment of their responsibilities in indigenous areas, the communities do not have the legal tools to change the situation, they can only report to the union, which paradoxically has as their highest priority to protect teachers' job security (Ornelas, 1995).

was their worry that their students are taught by teachers with low pedagogical training (see Table 4.2 for this category).

The adults and students of this community described their experience with the public education system and with science education as one in which they experience ethnic/linguistic discrimination, decontextualized instruction, and delegitimation of their knowledge. They also report that teachers are inadequately prepared to recognize the cultural resources indigenous students bring to the classroom. These issues are those described by other researchers working with indigenous communities in Mexico (Gómez Lara, 2010; Carnoy, et. al., 2003), the United States (Cajete, 1994; McCarty, 2003; CITES), Argentina (Padawer, 2012), and New Zealand (McKinley, 2007). These studies support my finding that students' prior knowledge is ignored, which stands in contradiction to well-accepted theories of learning. Students' experiences are part of their prior knowledge and are very real aspects of their day-to-day lives, thus playing a role in their motivation to learn and in the ways they prefer to learn. Framed in this perspective, the science classroom ought to be a space where students become empowered to construct and resignify their identities; that is, they should be in a position where they can decide how to enact their indigenous identity in different ways in different spaces (Gómez Lara, 2010), as opposed to the science classroom as a place that presses indigenous students to abandon their indigenous identities in the aims of learning Western science. To explore this approach, the following contextualization principles are aimed to support students in learning Western science while valuing their cultural narratives, and in opening spaces for them to use their Western science knowledge to challenge social unjust situations they or their communities face.

4.3.2.1. Contextualization Principles based on the Results of the Exploration of the Experiences Nahuas have with Public Science Education

The important issues presented in the last section were used to design contextualization principles oriented to create a science classroom where students do not experience assimilation and discrimination pressures; but on the contrary, one in which their language and traditional knowledge are valued as legitimate forms of knowing and develop critical thinking tools that allow them to use their knowledge of Western science to challenge the socially unjust conditions they face.

Principle 6: Valuing Nahua narratives and language through curricular materials. One strategy suggested by wise women and man of this community for teaching science so that it contributes to students' positive experiences in the public education system, was to support students in knowing and taking pride in their culture. This idea is aligned with Ladson-Billings (XXX) idea that students should develop cultural competence, and with Carter's (2004) idea that science education should not be an assimilation process in which students are led to believe that Western science is the only way to make sense of our world. Also, this perspective facilitates border crossing between different ways of explaining the world by understanding the two ways as equally legitimate. This is opposed to some forms of intercultural education, in which the incorporation of indigenous languages and traditions into the classroom is seen as a remedial measure. Here, students' traditional narratives, knowledge, and language are seen as resources and sources of pride. One example of this principle in the curriculum is presented in page 124:

Nombre Fecha

Let's Reflect 2.2
Nahua Science: Honey for Healing

As you learned in the prior reading, bees are very important for the reproduction of flowering plants. Moreover, bees produce a very important thing: honey.

Our Nahua ancestors used honey for healing. Through multiple observations and trials over years, they built valuable knowledge about the medicinal properties of honey. For example, the Nahuas of Santiago Yancuictlalpan in Puebla, mention a type of honey called "honey from small hive", very useful for sweetening medicinal infusions that cure from whooping cough and also used for curing some fungal infections common in baby's mouths by cleaning the insides of their mouth with this type of honey. In Huejutla, Hidalgo, the consumption of the so-called honey of the virgin is widespread. Thus type of honey is produced by a bee of the Trigona species and is used to regulate menstrual discharge, relief post partum pain, and as energizing tonic for elders.

In addition to all these properties of honey, before the arrival of the Spaniards to America, the ancient Mexicans used honey to avoid infections in wounds and burns, thus saving lots of people from disease or even death.

In 1985 a woman scientist born in England, Eva Crane, was interested in this knowledge about the medicinal properties of honey that Nahua people had. She did tests with this honey and discovered that honey had antibacterial effect, being specially effective against infection causing bacteria such as *Salmonella, Staphilococcus aureus, Micrococcus flavus,* and *Bacillus cereus.* From that moment honey has been successfully used in European hospitals as surgical cover because it is more comfortable that most bandages, and because it does not stick to the skin, wounds, amputations, extremely infected wounds, ulcers, or any type of lesion difficult to protect with bandages[3].

As you can see, what your ancestors knew about the medicinal properties of honey thousand of years ago, scientists discovered only 27 years ago!

MEANING MAKING

1. Is honey used for healing in your community?

____

____

[3] Diccionario Enciclopédico de la Medicina Tradicional Mexicana. http://www.medicinatradicionalmexicana.unam.mx/termino.php?l=1&t=miel%20de%20abeja

2. What are the characteristics of scientific knowledge?

____

____

3. What are the characteristics of Nahua traditional knowledge?

____

____

4. Do you think that the knowledge of your own culture can help scientists to better understand the world? Why?

____

____

5. According to what you have learned so far, do you think that scientific knowledge can help your community to better understand the world? Why?

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The above example introduces students to valuable knowledge derived from their culture that has been valued by Western scientists, even when those scientists have used different tools, language, and ways of thinking to make sense of that knowledge. The questions following the reading scaffold a discussion where students start thinking about the differences between Nahua knowledge and Western science knowledge. This discussion can also reflect about the complementarity of the two ways of knowing. It is worth noting that this reading (and others throughout the unit) was written with the specific purpose of students revisiting their traditional knowledge and developing pride in their tradition, a need manifested by the adults in the community. In this sense, this unit was contextualized in a liberatory manner (Freire, 1970), or in other words, in ways in which the needs of the community were heard and met, and not in ways in which the requirements of the national system are prioritized above the interests of the community.

Principle 7: Challenging the Status Quo and Developing Critical Consciousness. Discrimination and marginalization are vivid experiences for this community that have had an important effect on their access to post-secondary education and political participation. To ameliorate this negative effect an explicit focus in contextualizing this unit was to empower students to use their knowledge of science as a tool for socio political action (Roth & Désautels, 2002). This is consistent with one of the principles of culturally relevant pedagogy, namely that students must develop a critical consciousness through which they challenge the status quo of the current social order (Ladson-Billings, XXX). To operationalize this principle in the curriculum, several activities providing students with information and opportunities to question dominant narratives that discriminate them against, were added to the IQWST unit. One example of this principle is presented below

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Nombre Fecha

Let's Reflect 6.1
Is intelligence an Inherited Trait?

James Watson, the scientist who helped to understand DNA structure, gave a controversial interview in 2007, 54 years after his great discovery. When giving his interview for the English newspaper *Sunday Times* he said:

"There are many talented people in Africa, but I am inherently gloomy about the prospect of Africa because all our social policies are based on the fact that their intelligence is the same as ours, whereas all the testing says not really"

After reading this statement, the community of scientists around the world decided that the comment was not based on scientific evidence, and moreover, it was racist. Watson, the famous scientist said, was suspended from his university and he apologized to the media by saying:

"I cannot understand how I could have said what I am quoted as having said. There is no scientific basis for such a belief."[4]

After this event, many scientists gave declarations and offered clarification in the spirit of making it clear that there is no scientific evidence that any human race has traits for intelligence that others do not have. Scientist maintained:

"Defining intelligence is complex and there are many forms of intelligence – not all of which are captured by IQ tests"

To clarify even more, the scientist Colin Blakemore, a neurologist that studies the brain, said:

"In any case it would be as unethical to organize society around some numerical indicator of difference as it would to do so on the basis of skin color. Justifying discrimination on the basis of difference is utterly unacceptable."[5]

We human beings have migrated all around planet Earth, we have established different cultures, but there are only superficial differences among us, such as skin color. We humans all around the world are surprisingly similar.

MEANING MAKING

1. In the prior reading you found the word "racism". Discuss with your team what this word means and then share with all the class so you reach a consensus definition.

2. Similarly to what occurred in the United States and England with Watson's statement, here in Mexico, after the results of the ENLACE assessment for the last four years, some people have said that indigenous children are less intelligent than other children. Do you think that there is evidence to support that claim?

   Work with your team using the information in the Facts Sheet to write an article you would like to see published in a local newspaper.

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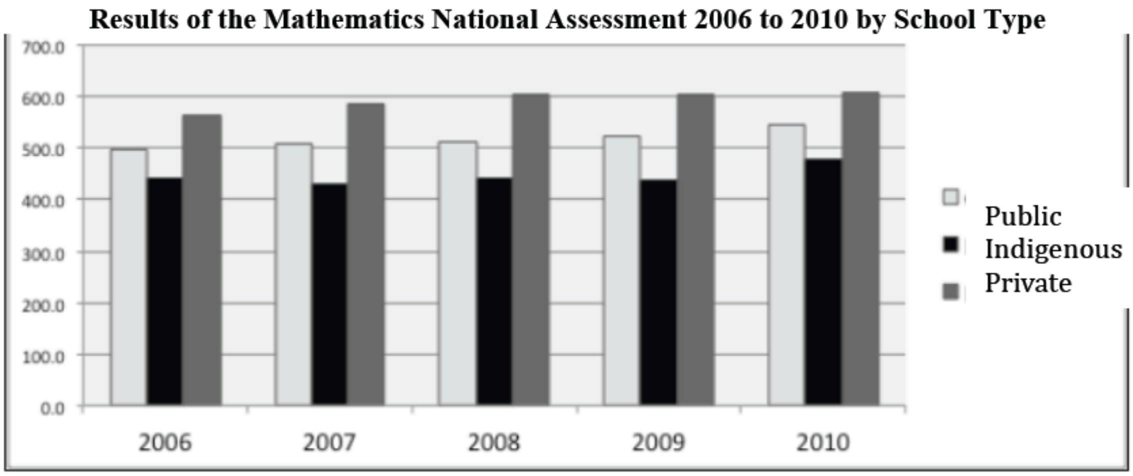
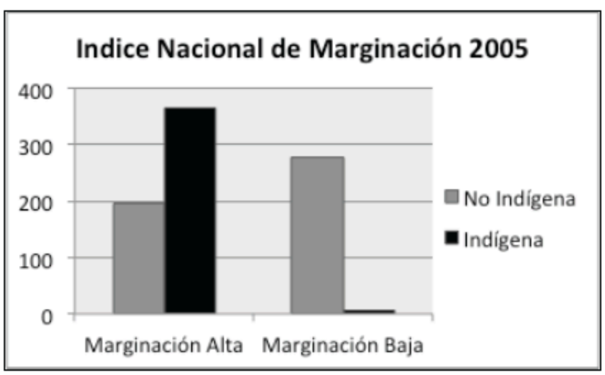
[4] http://www.nytimes.com/2007/10/19/science/19watson.html
[5] http://www.guardian.co.uk/uk/2007/oct/21/race.research

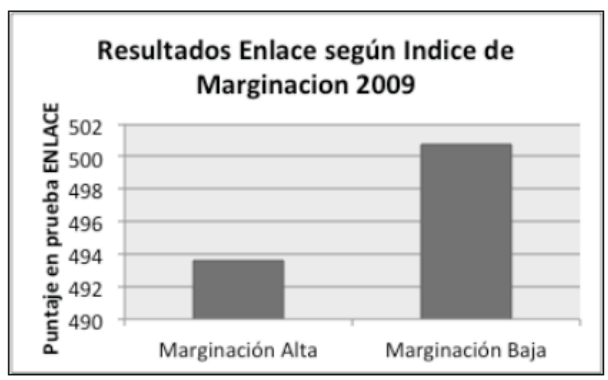
Facts Sheet



To better interpret the results in the graph, Mexican social scientists developed an index called "marginalization index." This index takes into account the following aspects:

- Poverty (access to food, income)
- Participation in the dominant culture
- Educational attainment
- Political participation
- Social participation





- What relationship you find between these two graphs?
- How do these graphs help you explain the results between the two graphs?
- Is there evidence to claim that indigenous children are less intelligent than other children?

Many people in our society, similar to Watson's case, say that there are countless examples of talented and intelligent people from all races and cultural groups. Next, there is a small list of outstanding indigenous people.

Rigoberta Menchú Tum

Rigoberta is a Mayan woman, born in Guatemala in 1959. Since her adolescence Rigoberta became involved in the movement of social reform. She speaks Quiche, other Mayan languages, and Spanish. Her fight for indigenous nations' rights has been tireless, to the point that she was awarded one of the most important recognitions in the world: the Nobel price in 1992.

Carlos Jacanamijoy

Carlos is a Colombian painter. He is a member of the Inga indigenous community in the Amazon forest. Carlos left his community when he was 18 years old to go to college. Once in college he used the myths and legends of his community as inspiration to create great artwork. Carlos is a famous artist today. He lieves in New York City (USA), but he travels frequently to his hometown where he actively participates in the traditions of his community, taking part in ceremonies and rituals –many of those led by his father, who is one of the "Curacas" or spiritual leaders of the community.-

Evo Morales Ayma

Evo Morales is the current president of Bolivia. He is a member of the Uru-Aimara community and he is a native speaker of Aymara. His parents were peasants and llama breeders. Evo started working since he was a child, combining school and work. He was a baker and a trumpeter, while learning about the rights of peasants and workers in his spare time. Later on he was appointed union leader and continued to have an active political participation until his election as president of the country in 2005 and his re-election in 2009. Evo is the first president of indigenous descent in the history of Bolivia.

Now that you have read about the results of the ENLACE assessment, the index of marginalization, and some outstanding indigenous people, write an explanation for the following question:

Do the results of the ENLACE assessment mean that indigenous children are less intelligent than other Mexican children?

Claim	
Evidence	

Use these lines to write the article you would like to see published in a local newspaper. The main topic of the article is how your science knowledge can help you fight against discrimination.

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The above example provides opportunities for students to use their knowledge of genetics and inheritance to question the oppressive narratives even when those are championed by prominent scientists. Also, students are encouraged to used representational forms (data, graphs) and discourses (evidence-based explanation) characteristic of Western science to challenge dominant narratives based on discrimination against ethnic/racial minorities. Learning about the results of the National assessment and about outstanding indigenous people may be both new and emotional experiences for middle school students in this community, therefore there is space in the activity for free writing (writing an article), so that students have additional opportunities to practice agency in using their knowledge and for processing their emotions. This activity is also designed to introduce students to the idea that Western science as human endeavor and therefore scientists can endorse different ideas and values, that students are in the position to support or challenge -using multiple sources of knowledge- as they see fit. These opportunities allow students to reflect upon their social context and use their traditional and Western science knowledge to be critical of socially unjust situations were added to the unit in the aim of supporting students in developing a critical consciousness by which they can challenge the status quo.

4.3.3. Contextualization Principles based on Culturally Based Norms of Interaction Leading to Learning

In this dissertation I have purposefully avoid the term “learning styles” because maintaining that any given ethnic group has an inherent “learning style” invites essentializing the whole group and facilitates the formation of stereotypes about particular groups of learners. However, from a Vygotskyan perspective, individuals learn through socialization processes that occur within their culture (1986). Because culture is shared and learned, these socialization processes unique to different societies lead to different cultural practices that favor particular forms of learning in different cultures. This is different from affirming that individuals in a culture are biologically predisposed to learn only in certain ways, or that their culture constrains them to the point of being able to learn only in a certain way. The main hypothesis of this section is that there are social interactions in the Nahua community that are conducive to teaching and learning and by adapting the IQWST unit in ways that it accounts for these preferred ways of learning, the opportunities to learn science for Nahua students can be maximized (Barton et al., 2013; Pewewardy, 2003).

I explored these culturally based norms favoring learning in this Nahua community by interviewing adult leaders of the community (wise men and women), as well as seventh grade students in the local middle school, and through ethnographic observation of life in Tequila (having lunch and spending the afternoon with different families in their homes, observing interactions in the produce market and church, etc.). Looking for patterns and regularities in the transcribed interviews and ethnographic field notes, it was evident that both adults and students conferred great importance to the role of elders (grandparents) as teachers and respected figures, and that knowledge and practices are usually learn by listening to conversations, narratives, or watching more experienced ones perform an activity (Table 4.3).

Table 4.3 Ways of interaction conducive to learning in the context of the Nahua culture (categories with more than 10 references shown in bold print)

Category	Number of Data Sources	References
Learn by doing or practicing	3	5
Learning by listening to oral narratives or conversations	**3**	**22**
Learning by watching them perform	2	7
Learning from elders	**3**	**21**
Motivation to learn comes from desire to serve the community	2	7
Motivation to learn usable skills or info in everyday life	2	4
Teach to love and respect nature	2	4

The two most common categories were "Learning by listening to oral narratives or conversations" and "Learning from elders." Both adults and students reported having learned important skills and knowledge from their grandparents. For example, Doña Catalina, a traditional midwife and healer shared:

> *Interviewer: Doña Catalina, all those things you have told me about medicinal plants, where did you learn that?*
> *Doña Catalina: well, from my grandparents because them, my grandparents, apart from other adults or elders from here [Tequila], they used to tell us what type of plant to use in case of stomachache, or for many other purposes.*

This pattern of learning from elders through oral narratives remains valid today, and it is still a practice in which middle school students are socialized. Students in Tequila still identify elders as a respected source of knowledge, as can be seen from the following focus group's excerpt:

> *Interviewer: is there someone in your community with great knowledge about animals and all the stories you have told me so far?*
> *María: only our grandparents*
> *Sandra: right*
> *María: and some mothers, some mothers are also knowledgeable*
> *Gabriel: our grandparents tell us all sort of stories.*

This is consistent with what other authors working with indigenous groups in the United States have reported regarding the central role of elders as teachers and figures of respect. For example, Apache and Navajo children become socialized into observing the lives of parents and grandparents as a source of valid knowledge (C. Pewewardy, 2002). In the Nahua community in Tequila this observation is usually centered in watching elders perform important skills and being motivated by how useful those learned skills will be for daily activities and for serving the community (Table 4.3). This type of focused observation has also been reported by Rogoff (2011) in her description of learning in the context of Mayan and Mexican indigenous communities, and is characterized here in the words of Augusto and Chela, wise people of this community:

> *Augusto: in my case for example, I grew up in my nana's ranch, she was in a certain way the midwife and healer of my ranch and because I was the youngest of my family I shared most of my childhood years with her. At that time I was not going to school yet because I was too young, so I used to go with her to the fields and she transmitted her knowledge to me. The little or as much as I know about herbs I owe to her, because she said "let's go to pick up some herbs" and she told me "this one is called this and it is used for that, this one is called sano and it is used for that, this one you mix with that to heal from cramps, this and that for a faster birth so the creature is born faster, if you have a fever you have to do this." This is what is called oral tradition right? What you inherit and that in my case, [sic] I had the fortune to share those childhood years with Clemencia. Clemencia was her name, rest her soul in peace, transmitted her knowledge to me and I was learning just by living with her, obviously because not all children lived with her, I was the lucky one.*

Augusto relates how as a learner he observed his grandmother's activities, and Chela describes below how her role as a teacher motivates her to serve the community and to support others in developing the same spirit of service.

> *<u>Interviewer</u>: I have been told that you are organizing the artisan women in the community, that you used to be a nurse and traveled all around these mountains as a nurse, also that you grew up here in Tequila speaking Nahuatl, and that you are involved in educational projects with Maestro Santos. You have done great work in this community.*
> *<u>Chela</u>: how glad I am to hear this because it is a personal satisfaction to be able to cooperate in the development of our community… I taught first aid and vaccine application to people in*

different communities, and after the first training session we would return to the community, twice a month we would return, in case they had questions or to give a talk in the community. There were three men and three women in one community [who participated in the training], well, well, well, they remain living in their community and some of them became nurses… Those people [that Chela trained] became nurses of community clinics and because they could speak the language [Nahuatl] they became interpreters mediating between doctors and patients. They became the link between health services and the community; they facilitated vaccination and information delivery. They became important people in their communities. They were motivated to learn to serve their community and their people.

Based on these reports from adults and students of the community I could infer that still today in this community students learning by apprenticing (Lave & Wenger, 2001), from storytelling, interactions with elders, and a desire to learn usable skills to serve their community. Therefore, elders or grandparents and learning skills that can be used for the benefit of the community should be included when designing science materials and instruction in a contextualized manner. These findings further support the validity of Principle 4: "Using traditional Nahua knowledge and practices as a context to explore Western science concepts and to engage adult members of the community in the classroom" as a culturally relevant principle. Moreover, because adults and students emphasized that they are used to learning by listening to more experienced individuals, a principle was added to the unit in which several readings were transformed into videos where one member of the community narrated the reading.

Principle 8: Including videos as a proxy for storytelling. By transforming several readings into videos it is expected that Western science knowledge can be socialized in a way that is familiar to students. Socializing information this way not only triggers student involvement, but also can help students who struggle with reading in Spanish, which is common among indigenous children in the Mexican system of education (Gómez Lara, 2010), by providing multiple ways of accessing information, thus facilitating their involvement and learning of science. One example of this principle is the transformation of reading 2.1 into a video where two young people of the community explain the story and concepts included in the original reading. This particular reading introduces students to the concept of PTC (phenylthiocarbamide) and how it was used for paternity tests. The reading introduces technical vocabulary and the context in which the events occur is unfamiliar to the students of Tequila (a laboratory in a big chemical company). Therefore, by transforming the reading into a story told by local people in a familiar context (a home) where they show how to use the PTC strips and make the story more accessible, it is expected that students can relate and engage in learning new and complex concepts. This approach was used to introduce both Western science concepts and traditional narratives that were the context to learn some of the concepts in the unit (principle 5).

Figure 4.9. Snapshot of reading 2.1 transformed into a video.

Nahua students learn by listening to elders' advice and stories and having time to observe and make sense of those narratives for themselves. This form of education is common for many Mesoamerican indigenous communities, where giving advice to children and youth is as an act of reciprocity where elders give back the knowledge they once received by their elders (Gómez Lara, 2010; Rogoff, 2011). Because this form of education is experienced in the context of family and community with multiple elders serving the role of teachers, it is difficult to reproduce this strategy in the classroom. However, it is expected that by frequently involving elders as visitors to the classroom and sources of knowledge that students consult, and by incorporating storytelling in the form of videos, the unit becomes more aligned with traditional learning strategies characteristic of the Nahua community, facilitating their access to the concepts included in the IQWST unit.

4.4. Summary of Contextualization Principles

Based on quantitative (teleology and essentialism) and qualitative (Nahua culture and experiences) analyses, a total of eight contextualization principles were conceptualized and guided the design of specific activities and examples throughout the IQWST unit on inheritance and natural selection (Table 4.4). These principles are grounded in a strong theoretical base but are hypothetical at this point. Empirical evidence of their effect on students' learning of science is presented in the following chapters.

Table 4.4. Contextualization principles guiding the design of activitites and scaffolds to be included in the IQWST unit.

Contextualization Principle
1: Using students' culturally based knowledge of living things as a context to understand complex concepts
2: Reflecting on teleological types of reasoning when applied to living things through the evaluation of inaccurate evidence-based explanations.
3: Using students' traditional indigenous knowledge as a context to understand Western science concepts (e.g. knowledge of the variability of traits in local plants to understand how external properties are linked to internal properties -relationship phenotype - genotype-)
4: Using traditional Nahua knowledge and practices to engage adult members of the community in the classroom as a gateway to explore Western science concepts.
5: Legitimizing students' traditional narratives and knowledge in the context of the science classroom, thus facilitating border crossing into Western science.
6: Revaluing Nahuatl language through curricular materials
7: Using science knowledge to challenge the status quo and developing critical consciousness
8: Including videos as a proxy for storytelling (a cultural practice associated with teaching and learning in this culture)

4.5. Conclusions: A New Process for Contextualization of Science Curriculum

Learning science with understanding can be considered a generative process of constructing meaning from our own knowledge, experiences with the world, new incoming sensory information, and narratives we hear from others and from the media in our culture. If this view of learning science is taken seriously, we then need to accept that learning science is a highly contextual process (Osborne & Wittrock, 1983), where students' understandings of the natural world can be used as substrates to develop their understandings of scientific concepts. Thus, from this constructivist point of view, it is critical that student's prior knowledge and experiences be taken into account during the teaching and learning process (Duschl, et al., 2007), so that they have opportunities to construct meaning by linking new information to relevant aspects of their lives.

However, accounting for students' prior knowledge and experiences has a deeper meaning beyond pre-testing students to find out what they learned in prior grades and providing them with examples coming from popular culture. Prior knowledge and experience is understood here as the ways in which we make sense of the world around us, which is a function of the cultural and historical context in which we develop in interaction with others. Therefore, prior knowledge and experience comes from the interaction between the psychological (individual level) with the sociological (community and institutions) and can only exist through language (Roth, 2010). We create and experience thought and culture only through language, and in turn, language-mediated interactions shape our thinking and worldviews (Vygotsky, 1978). It follows that a truly constructivist perspective in which cognition is seen as a construction of the learner based on their prior knowledge ought to include the dimensions of culture and language and socio-historical context.

Therefore, for designing curricular materials and instruction relevant to students it is necessary to learn about students' cultural-based practices, views, expectations, and norms, so that these aspects of student's lived experience become social and cultural resources that support their subject matter learning outside of the context of their communities –at school- (Lee, 2002). In this sense curricular contextualization remains a process of leveraging students' prior knowledge and experiences to foster understanding of challenging science concepts (Rivet & Krajcik, 2008). As important as this is, it is urgent to understand "challenging science concepts" not as the ultimate goal or hegemonic way of knowing, but as one of many possible ways of knowing students should have access to in order to live fulfilling lives in the societies and historical moments where they live.

Operationalizing the idea of multiple ways of knowing in science curricular materials implies recognizing that students employ a variety of means to make sense of the world. In the context of this study this implies recognizing that traditional Nahua knowledge and Western science knowledge are not competing discourses but "both/also" ways of approaching the understating of natural phenomena. This perspective allows for students' lived experiences and understandings to become foregrounded and valued as legitimate discourse in the science classroom (Tan & Calabrese-Barton, 2010).

In light of the findings presented in this chapter I am proposing a process of contextualization (fig. 4.9) to provide students with multiple opportunities to build on prior ways and knowledge made available to them both through their community life and through school science, and to scaffold the navigation of those multiple ways of knowing so that students understand how Western science knowledge is different or similar to their own culturally-based traditional knowledge (Aikenhead, 2001).

Within this process, the contextualization principles guided the design of scaffolds to support the comparison, reflection, and navigation of Nahua culture and Western science as valid ways of knowing. This comparison was framed in a way in which students gain autonomy in accepting, rejecting, or recombining those two ways of knowing. From this perspective, students make sense of multiple epistemological traditions autonomously and using their creativity, reinventing their identities in response to the challenges of their society. It is not up to me as a researcher, nor is it the goal of this contextualized curricular material to dictate what students in this community (or any) should believe or how they should reconcile their traditional knowledge with Western science knowledge.

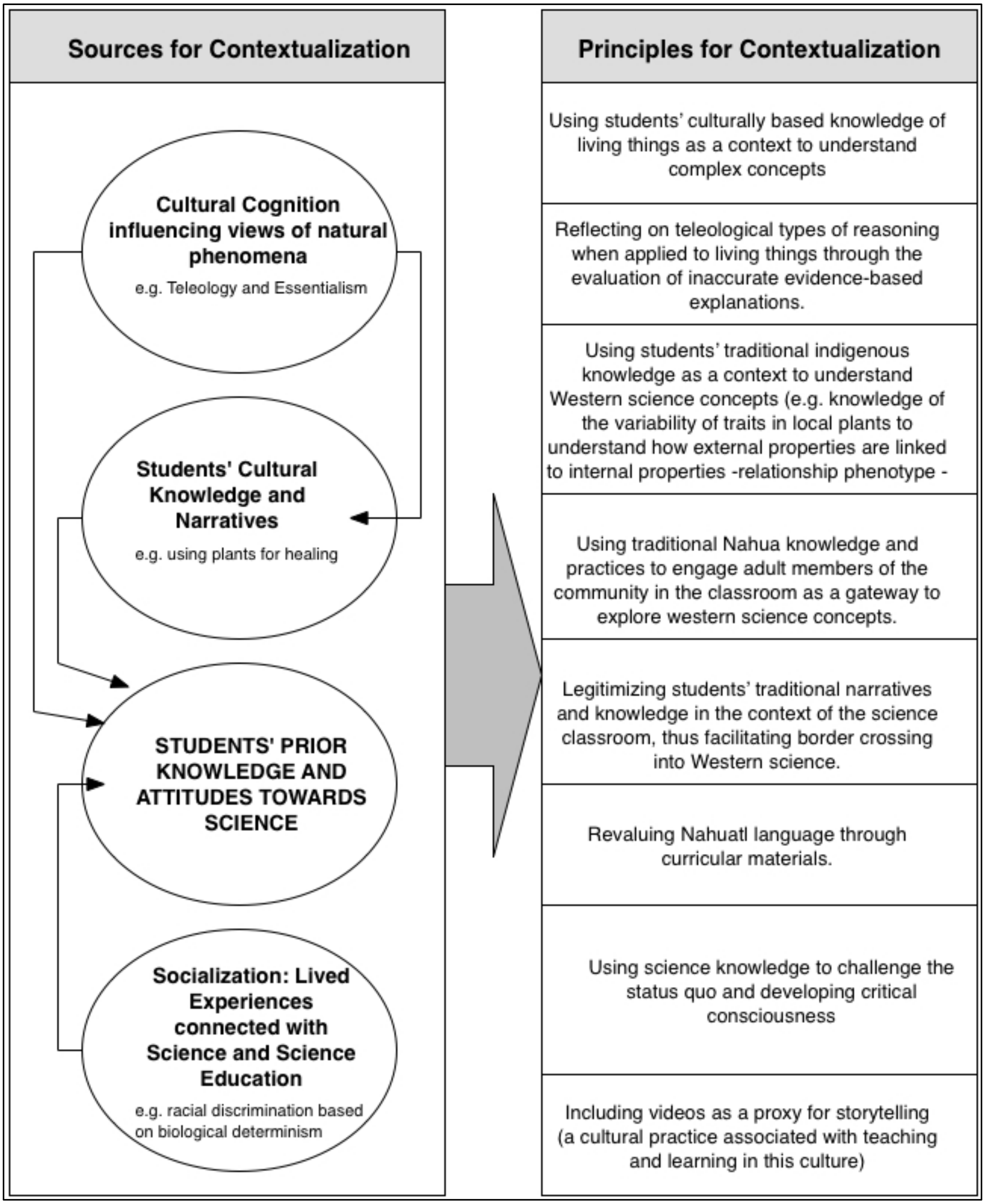


Figure 4.10. Process of curricular contextualization

This is a salient stance of this contextualization process, which aims to acknowledge power dynamics in which students are most often disempowered because of their young age –at school- and ethnic identity –in the Mexican society at large-, so that they can practice decision making and thus agency and empowerment while learning science.

It is therefore the goal of this contextualization process to provide ethnic minority students with opportunities equal to those available to their privileged peers (White in industrialized countries, or Mexican urban mestizos in this particular case) to access Western science. It is also my goal to scaffold a fluid border crossing between the two forms of knowing in ways in which students can succeed academically according to National standards and grow proud of their culture according to their own in-flux cultural norms.

This border crossing between Western science and traditional Nahua knowledge is addressed in this contextualization process by assuming that an asymmetrical relationship has historically existed between ethnic minority students and society, and that explicitly addressing this asymmetry will favor ethnic minority students' academic success by preparing them to combat inequity on the basis of their Western science and traditional knowledge in highly competent and critically conscious ways (Ladson-Billings, 2006). Addressing social injustice in science curricular materials can become a deeply situated way of science learning in the sense that it creates powerful need-to-know situations fruitful for fostering students' cognitive engagement in learning science (Sadler & Dawson, 2012). For example, in this IQWST unit student were given the opportunity to use their knowledge of genetics in a critical way to understand and challenge dominant narratives that have historically used Western science knowledge as justification for discrimination (e.g. biological determinism).

Finally, this process of contextualization aims to engage students in authentic practices not only of Western science but also of their own culture. Incorporating authentic practices of the students' culture into the science classroom has the potential to facilitate students' learning. For example, in Nahua and other Mesoamerican communities children's opportunities to be part of the community life are powerful sources of learning (Rogoff, 2011), as they can become engaged in most community practices, and participate in discussions. This process is always supported by the advice or their elders who provide opportunities for them to develop and perfect skills and knowledge necessary for the roles they are expected to have in their communities. Such a cultural approach to learning can be incorporated in science instruction by engaging elders in the classroom, and giving students opportunities to observe and participate in Western science practices out of their own need to make sense of an idea or a phenomenon and not because they have to comply to rules imposed by the teacher or a Westernized school system. In doing so, the discontinuities between the culture of Western science and students' cultures can come to function as resources for teaching and learning.

CHAPTER 5: EFFECT OF CONTEXTUALIZED CURRICULUM ON TELEOLOGICAL AND ESSENTIALIST REASONING PATTERNS

5.1. Introduction

According to multiple studies in science education and developmental psychology evolution is one of the most difficult scientific theories to teach –and learn- in science courses. This challenge is due to the numerous preconceptions and reasoning patterns that students bring with them to the classroom and that seem incompatible with the idea of a causal mechanism of descent with modification (Beardsley, 2004; Beardsley, et. al., 2012; Jay B. Labov, 2012; Zohar & Ginossar, 1998). According to a recent report of the National Academy of Sciences (Jay B. Labov, 2012) there is still much to learn about how students learn evolution and how to design effective instruction and curricular materials for all students to learn core concepts such as natural selection. An emerging question throughout the report not only concerns how to develop effective curricular materials, but how can the effects of those materials and instructional approaches be measured, opening avenues for further research. In this dissertation I am measuring the effects of a curricular unit on inheritance and natural selection that was contextualized for Nahua students, as described in the prior chapter. The effects of the unit on students' learning are measured through the convergence of multiple methods, tackling several aspects that have been reported to be obstacles in the learning of evolution. To be more specific, I am not only exploring learning gains in conceptual understanding of natural selection through pre and post-test, but also exploring the effects of the unit on 1) students reasoning patterns that have been widely reported to interfere with learning natural selection -teleology and essentialism- (Gelman, 2012; Kelemen, 2012; Zohar & Ginossar, 1998), and 2) students' ability to navigate Western science explanations about biological diversity and their own culturally based explanations on the same topic. In this chapter I will present the main finding that learning with the contextualized unit did not have an statistically significant effect on either the students' teleological or essentialist reasoning, although a significant learning gains regarding content was observed. I will provide possibe explanations for these results, moving from providing overall conceptual learning gains to explaining the effect of the unit on students teleological and essentialist reasoning, and finally providing suggestions for effective teaching and learning of natural selection.

5.2. Effects of the unit on students' teleological reasoning

Teleology and essentialist biases are deeply ingrained in human thinking, especially when people attempt to explain concepts such as inheritance and natural selection (Kelemen, 2012). Those reasoning patterns, as explained in prior chapters, have been demonstrated to be held by individuals in multiple cultures and are present in Nahua adults and 7th grade students (see Chapter 4). Because both teleological and essentialist biases have been reported to become pronounced when individuals have limited knowledge of causal mechanisms in a given domain (Gelman, 2003; Kelemen, 2009), I am presenting here learning gains regarding students' conceptual understanding of inheritance and natural selection, so as to provide the reader with an idea of students' conceptual understanding after they completed the unit. To assess content knowledge, a multiple-choice 15-item test was applied before and after completing the biology unit. Eight items of the test were taken from the Conceptual Inventory of Natural Selection – CINS- (Anderson, Fisher, & Norman, 2002), a well validated assessment that has been used in several studies to explore conceptual understanding of natural selection[6]. The

[6] After a thorough search for research studies in databases, I could not find a single study reporting information about middle school students' performance on the items included in the CINS. Therefore, I cannot compare how the

remaining seven items were developed by the IQWST developers to assess students understanding of the model of inheritance and the role of variation within populations.

The pre-test was taken by 65 students, but due to one teacher withdrawing from the study and student attrition, 35 students took the post-test. The difference between pre and post-test scores was significant and with an effect size of 0.42 SD (M1=4.62, M2=6.86; $p<0.01$). I present effects in standardized effect sizes and interpret them as a student completing the unit and taking the post-test gained on average 0.42 SD more than average on the pre-test. Because students received no other instruction related to the concepts on the test but the IQWST unit, the learning gains can be attributed mainly to the effect of the unit.

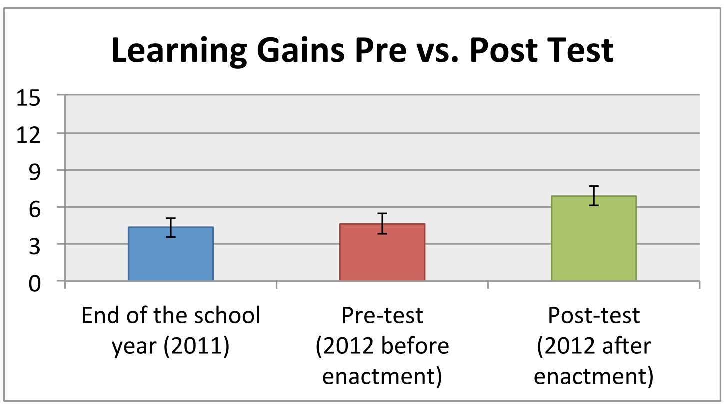


Fig 5.1. Average number of correct items in the pre and post tests.

Although the learning gain can be described as medium size and statistically significant, this is a measure of students' learning only in terms of standardized test items. Students in indigenous elementary schools rarely take multiple-choice tests and exhibit difficulties in reading comprehension when taking this type of assessment. In Mexican public schools indigenous population students take compulsory national standardized assessments for the first time by the end of the first year of middle school. In my study, none of the students had taken a multiple-choice test before. While

Nahua students in the present study compare to other populations of middle school students, other than the U.S. students who participated in the field trials of IQWST.

students with high achievement in Spanish (i.e. Language Arts) took an average of 20 minutes to complete the test, about half of the students required up to 60 minutes, asking for clarification frequently. Moreover, the IQWST did no prepare students with multiple choice tests taking skills, because the focus of the unit is in scientific explanation construction and argumentation. Therefore, the learning exhibited by students, although substantial, may be underestimated by this type of measure. To have a more accurate measure of students' learning other sources of information are needed (e.g. students' artifacts, class dialogues between students, etc.). These other forms of evidence on student learning will be discussed in detail in the following chapter, here I am including information about learning gains to provide evidence that by the end of the unit students had gained knowledge about the causal mechanisms of inheritance, population change, and natural selection, so that their essentialist and teleological tendencies cannot be fully attributed to limited knowledge of this conceptual domain.

Two contextualization features were designed to address the teleological patterns of reasoning 7th grade students exhibited when thinking about animals and plants:

- Feature 1: Using students' culturally based knowledge of plants as a context to understand complex concepts such as artificial selection
- Feature 2: Confronting teleological types of reasoning when applied to animals through the evaluation of inaccurate evidence-based explanations.

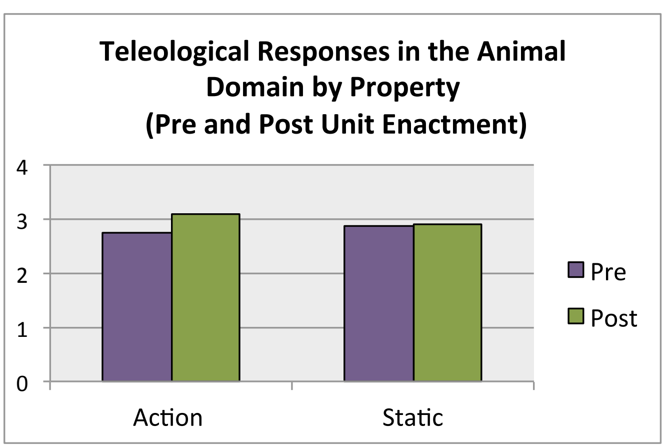
Working from the student and adult results from the teleology interview that provided information to contextualize the unit, I was able to take advantage of the students' preference for causal reasoning when thinking about plants, and emphasized the inadequacy of teleological explanations in the context of Western science, using predominantly static features of animals (for which the scores in the teleology interview were the highest). However, as was discussed in chapter 4, it may be that not all types of teleological reasoning are the same. Teleological statements may indicate that individuals are anthropomorphizing plants and animals or attributing agency to them. Although such statements pose obstacles to understand the causal process of natural selection (Zohar & Ginossar, 1998), teleological statements may be of a type that indicate relational thinking in the sense that an animal or plant may serve a purpose for a human activity or for another organism; this does not suggest the attribution of agency to non-human living kinds (Ojalehto et al., 2013).

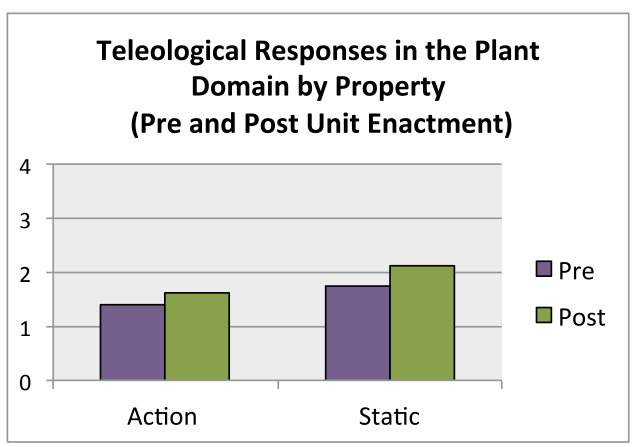
My hypothesis was that after learning with the contextualized unit that included the two features to specifically address teleological reasoning, students would exhibit a lower frequency of teleological reasoning leading to anthropomorphic explanations, but not necessarily a lower frequency of teleological responses of the kind that indicates relational thinking. This hypothesis was reasonable because the two features were designed to specifically address the former type of teleological stances. A second hypothesis is that the less strong the teleological bias, the higher the chance that students would understand and apply causal mechanisms characteristic of Western science knowledge (e.g. use the concepts of inheritance and natural selection in their responses). The basis for this rests in the literature reporting that teleology is a bias that is pronounced when there is a lack of knowledge of causal mechanisms for a certain phenomenon (Bailenson, Shum, Atran, Medin, & Coley, 2002; Evans & Rosengren, 2012; Kelemen, 1999).

These hypotheses were tested by conducting three repeated measures ANOVAs, one for responses coded teleological, the second for responses coded causal, and the third one for responses coded “self”-attributing agency to living kinds- or “other” – denoting a purpose for humans or other organism- (see coding protocol and methods in Chapter 4). Because the frequency of teleological responses for non-living natural kinds was markedly low for adults and students in the pre-contextualization stage, the interview was modified to exclude that domain. The interview was conducted the week before starting the unit, during the second week of the school year. Forty 7th grade students in three classrooms were randomly selected to participate in the interview, but one student never returned the parental consent form; thus, the total sample for the pre interview was 39. The same interview was repeated with the same students the week after completing the unit, but because one teacher withdrew from the study, the students in that classroom were not interviewed and the total sample for the post interview was of 32 students. Pre and post interview scores were used as the between group factor, while domain (animals and plants) and property (action and static) were used as within factors.

5.2.1. Results

Contrary to the hypothesis, students did not show a significant change in the frequency of teleological answers of any kind based on the comparison of the pre and post interview scores ($F(1,69) = 2.027$, $p > .05$, $\eta^2_p = .029$). For both domains (animals and plants) there was a slight but not significant increase in the frequency of overall teleological responses for action and static properties (Fig. 5.1). There was a marginally significant domain x property interaction for both the pre and post interviews, where students tended to provide more teleological responses for animals than for plants, and more teleological responses for static features than for action features, although the effect size –partial eta squared- is small accounting for only 9% of the effect + error variance ($F(1,69) = 6.94$, $p < .01$, $\eta^2_p = .09$).





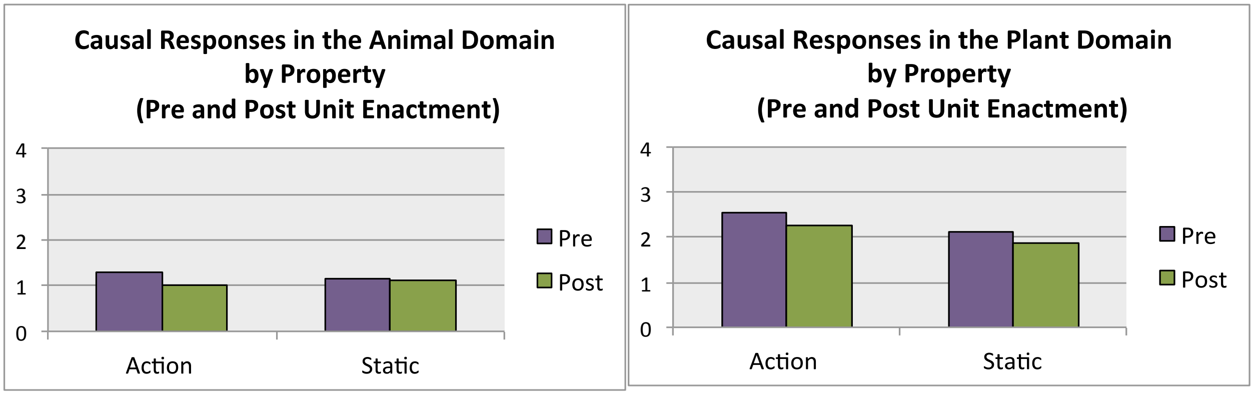


Fig. 5.2. Average score of teleological responses by domain and property for the interviews pre and post unit enactment. There were four items for each block –domain x property- so that the maximum possible score is 4 and the minimum is 0.

In line with these results, there was no significant difference in the frequency of causal responses for the pre and post interviews ($F(1,69) = 0.65$, $p > .05$, $\eta^2_p = .009$). For both the pre and post interviews there was a non-statistically significant tendency for students to provide more causal responses for plants than for animals, and more causal responses for action features than for static features (Fig. 5.2).

Figure 5.3. Average score of causal responses by domain and property for the interviews pre and post unit enactment. There were four items for each block –domain x property- so that the maximum possible score is 4 and the minimum is 0.

To better understand these results, all the responses coded teleological were further coded as “self” (responses indicating agency and self benefit) or “other” (responses indicating a function served for other organism –relational thinking-). This allowed for a finer grain analysis of the types of teleological thinking that students were engaging in before and after the unit enactment. I found no significant difference of the frequency for “self” responses pre and post interview ($F(1,69) = 108.64$, $p = .017$, $\eta^2_p = .008$). However, there was a significant domain effect for both pre and post interview scores, with a higher frequency of “self” responses for animals than for plants ($F(1,69) =$

5.98, p <.001, η^2_p = .62). This means, that the domain effect accounted for 62% of the effect + error variance for teleological "self" responses (Fig. 5.3).

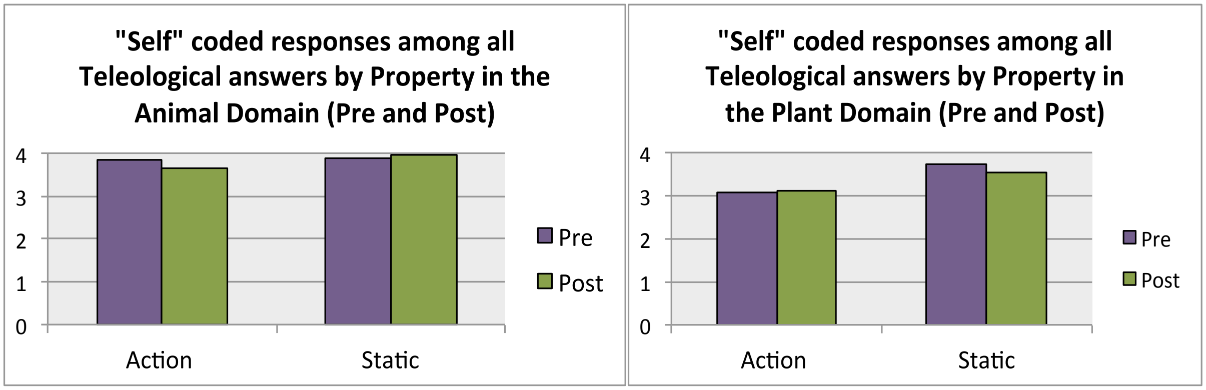


Figure 5.4. Average score of "self" responses by domain and property for the interviews pre and post unit enactment.

Students privileged "self" responses rather than "other" responses. However, a close look at the responses by item, reveals marked differences in the self vs. other preference. It seems that the "self" responses were provided for the oak, tomato, and cactus items mainly, with a very low frequency of "self" answers for avocado and corn, and not a single "self" response for the dandelion, mayflower, and leaf items (Fig. 5.4). In the case of the animal domain, the overall preference was for "self" responses across items, except in the case of dogs, where the preference was for "other" responses, especially after the enactment of the unit (Fig. 5.4).

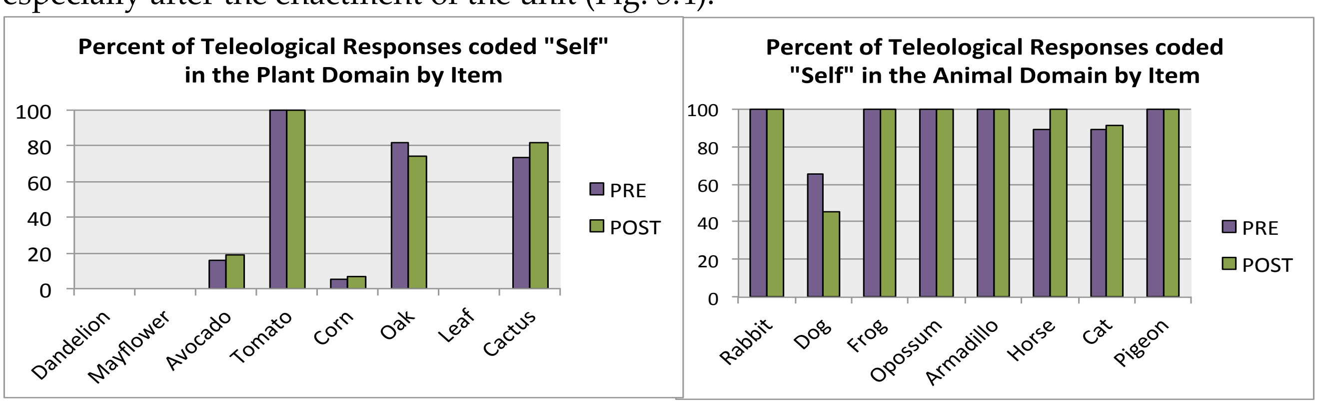


Figure 5.5. Percent of responses coded "self" among all responses coded teleological by item for a) Plants and b) Animals.

Finally, I hypothesized that the less strong the teleological bias, the greater the likelihood that students would understand and apply causal mechanisms characteristic of Western science knowledge (e.g. inheritance and natural selection). Because the students in this study tended to frequently engage in causal reasoning when providing explanations about plants (before and after the enactment of the unit), I tested this hypothesis to understand whether the causal responses provided by them invoked Western science knowledge (WSK) or not, and whether there was a change in the use of WSK before and after the enactment of the unit. The results confirm the hypothesis: there was a significant domain effect with students using WSK at a higher frequency for plants than for animals ($F(1,69) = 7.0$, $p < .01$, $\eta^2_p = .09$); and there was also a significant domain x property effect, with students using WSK at a much higher frequency for static features of plants and animals than for action properties ($F(1,69) = 1.62$, $p < .05$, $\eta^2_p = .02$) (Fig. 5.5).

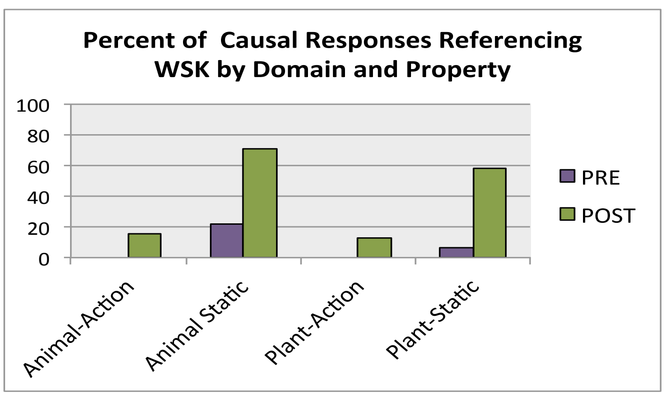


Figure 5.6. Percent of causal responses referencing WSK by Domain and Property

5.2.2. Discussion

Although there is no significant pre-post difference in the frequency of responses coded teleological, there is a significant increase in the frequency of causal responses in which students applied concepts of Western science that they learned during the enactment of the unit (e.g. inheritance and natural selection). These results seem to indicate that the features included in the unit did not have an effect on the students' tendency for teleological reasoning, but did help students to learn Western science concepts such as inheritance and to apply them when reasoning about plants and animals. Thus, the observed teleological bias does not seem to interfere in students' understanding and application of biological causal mechanisms such as inheritance, contrary to what other studies have found (Gregory, 2009; Kelemen, 2012; Nehm & Ridgway, 2011).

The persistence of the students' teleological tendency after eleven weeks learning about inheritance and natural selection in a culturally relevant manner lends support to Kelemen's (1999, 2012) view that teleology is a powerful human bias that leads to see properties of organisms as existing for a purpose. In view of this continued instruction across multiple grades may be necessary to observe significant changes in teleological patterns of reasoning, which cannot be achieved in a very short period, as in the 11-weeks of instruction for this study. Although Kelemen argues that teleological reasoning is promiscuous across domains (especially for children), the results of my study suggests a clear and significant difference in students' teleological reasoning about plants and animals for both the pre and the post-test (being less teleological for plants). These results are consistent with the results of the pre-contextualization teleology interview, suggesting that the rich culturally based knowledge that students have of plants in the Nahua culture may lead individuals to prefer causal explanations for plants rather than teleological ones. In this sense, I agree with Kelemen that there is a powerful human bias for teleology, but contrary to her argument (Casler & Kelemen, 2008; Kelemen, 1999, 2012), the results here seem to indicate that this bias is constrained by cultural views, but does not necessarily indicates intentionality or interferes with an accurate understanding of inheritance or natural selection.

The claim that teleological reasoning is culturally constrained is further supported by the fact that students did not use the same type of teleological reasoning for plants and animals, and not even for all animals or all plants. The frequency of “other” responses was significantly higher for plants, especially for those plants that are used in traditional healing (dandelion, mayflower, leaves) or are the base of their diet (corn), which indicates a functional type of teleological reasoning (serving a function for other -humans) but not a type of teleological reasoning denoting desire (anthropomorphic) or need (of the plant/animal to survive). On the other hand, students preferred “self” teleological responses for animals, except for dogs, which have an important role in the Nahua culture as guardians/protectors of people’s homes and as helpers in the after-life path. These results provide additional support for the idea that teleological cognitive tendencies may not only stem from a framework of implicit underlying intentional assumptions about nature (Kelemen, 1999, 2012), but also from relational views of nature that are more prevalent in some cultures and may lead to a strong purpose-based bias when certain living kinds serve a function for human activities or other living kinds (Ojhaleto, et. al 2013). These results question the idea that that all teleological stances represent a default assumption that influences the construction and persistence of students’ scientifically inaccurate causal theories about natural selection (Kelemen, 2012). This may hold valid for the desire- or want-based type of teleology that denotes intentionality (Evans & Rosengren, 2012), but not for function-based teleology, as the students in this study reported substantial learning gains in the conceptual knowledge test and exhibited a significant increase in their accurate use of Western science concepts despite not showing any decrease in the frequency of their teleological responses. Taken together, the findings here raise question whether Kelemen’s (2012) proposal that children compensate for their lack of knowledge of scientifically valid physical-causal explanations of natural phenomena by drawing on their knowledge of the domain of intentionally designed artifacts. In the Nahua context, the teleological tendency did not change after students learned about natural selection and inheritance (scientifically valid physical-causal mechanisms), but based on the learning gains, students’ artifacts, and dialogues during classes, there is good evidence that students did understand those concepts. Therefore, a lack of knowledge of scientifically valid physical-causal mechanisms does not seem a strong candidate to explain the cause of students' preference for teleological responses.

One explanation for this discrepancy may be that the conclusions reached in other studies (Casler & Kelemen, 2008; Kelemen, Rottman, & Seston, 2012; Kelemen, 1999, 2012; Lombrozo, Kelemen, & Zaitchik, 2007) are based on studies that required participants to choose between two explanations, the scientifically accurate one and the teleological one. Such a design would be effective if there is only one type of teleological reasoning, but this does not seem to be the case. By not allowing participants to freely provide explanations information about the different ways in which individuals engage in teleological reasoning is lost, leading to overgeneralizations. Moreover, a design based on having participants choose between two answers requires participants to engage in dichotomic thinking (which is not privileged in certain cultures as the Nahua) and penalizes respondents for their lack of scientific knowledge. Faced with a choice between options, participants may choose the teleological option because it sounds more like daily language and therefore appears plausible rather than making a choice because they ascribe intentionality to natural objects. Given the latter possibility, it makes sense that the results of this dissertation, based on a freely provided explanation design –open ended questions-, resulted in different and more nuanced findings than those of prior studies on teleology (Casler & Kelemen, 2008; Galli & Meinardi, 2011; Kelemen et al., 2012; Kelemen, 1999, 2012; Lombrozo et al., 2007).

The fact that the observed tendency to focus on function or purpose did not impede students' use of Western science concepts in their responses may indicate that 1) students engage in teleological reasoning as an intuitive or short-hand way of talking about traits of animals and plants, and 2) students engage in a type of teleological reasoning that is not desire-based (intentional/anthropomorphic) or need-based, but function-structure based. More specifically, all the teleological responses coded in students' answers were non-intentional, supporting Zohar & Ginossar (1998), who proposed that students' teleological responses denoting function (not intention) are a shorthand for explaining biological processes when students do not have the elaborated and sophisticated language scientist use to avoid teleological statements. For example, students did learn about the relationship between structure and function during the enactment of the unit, which is easily explained in statements that can be deemed teleological. To explain the living kinds structure-function relationship without engaging in teleological reasoning a high level of sophistication and content knowledge is required. For example, one may say that the function of the protein fibrinogen in blood is coagulation. A hematologist would agree with the statement "the structure of fibrinogen is similar across mammals so that it can perform its coagulation function"; however, this is a teleological formulation. Only if you specify that you need a causal statement that more fully describes the structure-function of fibrinogen, a hematologist would say something along the lines of "Fibrinogen is a protein composed of six polypeptide chains that participates in blood coagulation. The fibrinogen structure is highly conserved among mammals because changes –mutation- in this protein that may compromise its ability to participate in the coagulation process may lead to the death of the individual. Thus, the evolutionary pressure for structure stability is high." This level of sophistication is characteristic of evolutionary biologists or paleontologists but not even biology college majors succeed at avoiding teleological responses when explaining function (Rector, Nehm, & Pearl, 2012). Therefore, it does not seem reasonable nor is it fair to underestimate their knowledge of scientifically valid causal mechanisms because they do so.

Studies involving follow up questions to better understand students' teleological responses have concluded that high school students' acceptance of teleological formulations do not necessarily imply anthropomorphic or teleological reasoning (Zohar & Ginossar, 1998) and that biology majors rarely engage in need-based or desire-based teleological reasoning but predominantly engage in function-based teleology, perhaps because they have not mastered the nuances of scientific language, thus using everyday language as a synonyms or 'filler-terms' (Rector, et. al., 2013). The study presented here involve asking students follow up questions; however I will present other sources of data that further demonstrate that the middle school students who participated in this study, similar to high school students and biology majors in the above-described studies, did not endorse an intentional or need-based teleology.

5.2.2.1. Effects of Principle 1 on students' reasoning patterns. Using students' culturally based knowledge of plants as a context to understand complex concepts such as artificial selection. Based on the above results I conceptualized principle 1 to guide the design of activities addressing students' teleological reasoning patterns. Opportunities for students to read and talk about traditional techniques and knowledge of their culture and communities regarding plants were included throughout the unit as a way to start thinking about topics such as within-species variation, inheritance, and population change. After completing readings or group discussions students were asked to build evidence-based explanations or to critique an already given explanation. After reviewing the complete sample of students' notebooks I found no instance in which students used desire-based or need-base teleology (need of the organism to survive) as claims or reasoning for their explanations. When they did not use causal reasoning they used function-based teleology (the organism serving a function for humans). For example, in chapter 4 the example I provided for principle 1 was a text where students had the opportunity to learn how due to the knowledge and agricultural technologies of Mesoamerican and South American indigenous groups, the corn plant was selectively bred into most of the modern varieties we know. After having read and discussed this text students were asked to write a scientific explanation (claim, evidence, and reasoning) in response to the question: "Why are there so many varieties of corn?" The explanations constructed by the students were causal, or a mixture of causal and function-based teleological reasoning. One example representative of a mixture of causal and function-based teleological reasoning is presented below.

¿Por qué hay tantas variedades de Maíz?

Aseveración *Claim*	Los elotes tienen muchas variaciones en sus caracteres y como su adn *Corncobs have many variations in its traits and like [sic] its DNA.*
Razonamiento *Reasoning*	El maiz es una planta con muchas variaciónes que se han seleccionado por el entre cruzamiento selectivo *Corn is a plant with many variations that have been selected by selective crossbreeding.*
Evidencia *Evidence*	Aqui en tequila y en otros municipios utilizamos el maiz para diferentes cosas *Here in Tequila and in other municipalities we use corn for different things.*

In this type of explanation students use Western science Knowledge (WSK) of DNA, traits, selection, and change. However, the evidence this student is providing does not come from WSK but from her knowledge of how corn is used in her community. This example is not intended to show that this student built an accurate scientific explanation with strong evidence, but to indicate that the student seems to recognize the mechanism of change over time (crossbreeding) but believes that the mechanism underlying this process is the use they make of corn in her community. In other words, in the Nahua world specific varieties of corn are used for different and specific purposes (e.g. feeding animals, making tortillas, boiling corncobs to be eaten with cheese and chili, etc.), thus it makes sense for students that because people need to use corn in such different ways, they crossbreed it and select it until they have the current varieties they know. In this sense, the purpose corn serves for humans is the driver of the process for this student (and therefore the explanation has an evident teleological component). Interestingly, this type of thinking is not incompatible with valid scientific explanations of crossbreeding and can constitute a point of departure for students to continue refining their understanding of natural selection until they achieve a more sophisticated and accurate explanation of the causal mechanism of natural selection. Although it would be desirable to have detailed information on the types of teleological thinking that the students engage in when thinking about natural selection, the coding scheme I used does not allow establishing a difference between function-based, need-based, or desire-based teleology. To have a finer grain analysis on different types of teleology I used "self" and "other" as proxies (see chapter 3). Therefore, responses such as "corn has kernels so that we can eat it" are coded as "other" because corn is serving a purpose/function for other organism. Because principle 1 used only examples with plants, emphasizing corn, it makes sense that students privileged "other" responses for plants, but not for animals. Also, students' constructed explanations support the idea that function-based teleological reasoning seems not to interfere in students' learning and application of scientific causal processes. These results coincide with the findings of Ware & Gelman (2013) that teleological reasoning is more frequent in undergraduate students when they consider the inheritance of features with functional implications. However, based on the students' explanations I partially disagree with these authors that teleological reasoning violates modern evolutionary principles, and I propose that function-based teleological reasoning can be a stepping-stone for students to develop a completely causal explanation of natural selection. Complete avoidance of teleological explanations in evolutionary reasoning may be only achieved with the deep content knowledge of biology and epistemological understanding of science that is achieved by scientists (Rector et al., 2012; Zohar & Ginossar, 1998; Nehm & Ridgway, 2011). In other words, what is required is years of enculturation in the discipline of biology and very sophisticated content knowledge to avoid function-based teleological biases when reasoning about evolutionary processes, especially when the relationship structure-function is taught and emphasized from the early elementary years up to high school (Catley, Lehrer, & Reiser, 2005). Therefore, it may not be realistic to expect middle school students avoid engaging in function-based teleological reasoning. And when they do, this should not be an indication that their reasoning is naïve or that they are not learning valid causal mechanisms characteristic of WSK.

5.2.2.2. Principle 2. Reflecting on teleological types of reasoning when applied to animals through the evaluation of inaccurate evidence-based explanations.

As described in the prior section, function-based teleology does not seem to interfere with students' learning of natural selection. However, desire-based or need-based teleology in which students understand inheritance and natural selection as intentional process driven by goal-directed behaviors of individual organisms can pose a significant obstacle to understanding natural selection as a causal process. For this reason, feature 2 focused on having students evaluate and critique explanations using desire-based and need-based formulations as the main reasoning. Despite the teleological bias exhibited by students, they found this type of teleological formulation implausible. For the example of this principle provided in chapter 4, students had data about the change in the frequency of a static trait (color) in a population of ladybugs. They were given two explanations that they had to evaluate in terms of accuracy. If they found them inaccurate they had to explain why and build a new, accurate explanation (Figure 5.7).

Why did the distribution of ladybugs change?

LUPE		ÁNGEL	
Claim	*Melanic ladybugs living far from the coast realized that the air was warmer and decided to start reproducing, because now they could stay more active and obtain food.*	**Claim**	*Melanic ladybugs were dark so they could stay active in cold places. Now that the climate changed they do not need to be dark anymore, but they need to protect themselves from predators, so they became red.*
Evide nce	*In 1980 45% of the non melanic ladybugs lived far from the coast, now that it is warmer 78% of the non melanic ladybugs live in this place.*	**Evide nce**	*In 1980 45% of the non melanic ladybugs lived far from the coast, now that it is warmer 78% of the non melanic ladybugs live in this place.*

Fig. 5.7. Example of explanations based on teleological formulations that students evaluated as part of the proposed activities in the biology unit.

After reading these explanations and discussing them in pairs, the students engaged in a group discussion, some of which is presented here in order to illustrate students' reasoning:

Group 1:

Student 1: *There is a question here that says that melanic ladybugs were dark so they could stay active in cold places but now that the climate changed they don't need to be dark anymore, and now they have to worry to get protection from predators so they are becoming red. But how can it be explained that they are becoming red?*

Teacher: *What do you think about that, what is strange about that explanation?*

S1: *That they are becoming red. I don't think they can change by themselves.*

Group 2:

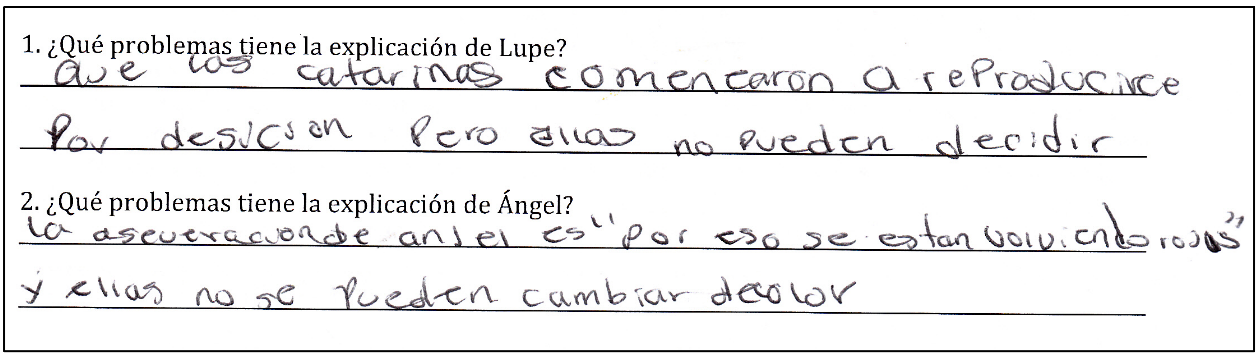
Student 2: *It says that ladybugs change color, but they cannot change color by themselves.*

Teacher: *exactly, so?*

S2: *This is wrong.*

T: *remember to consider inherited traits.*

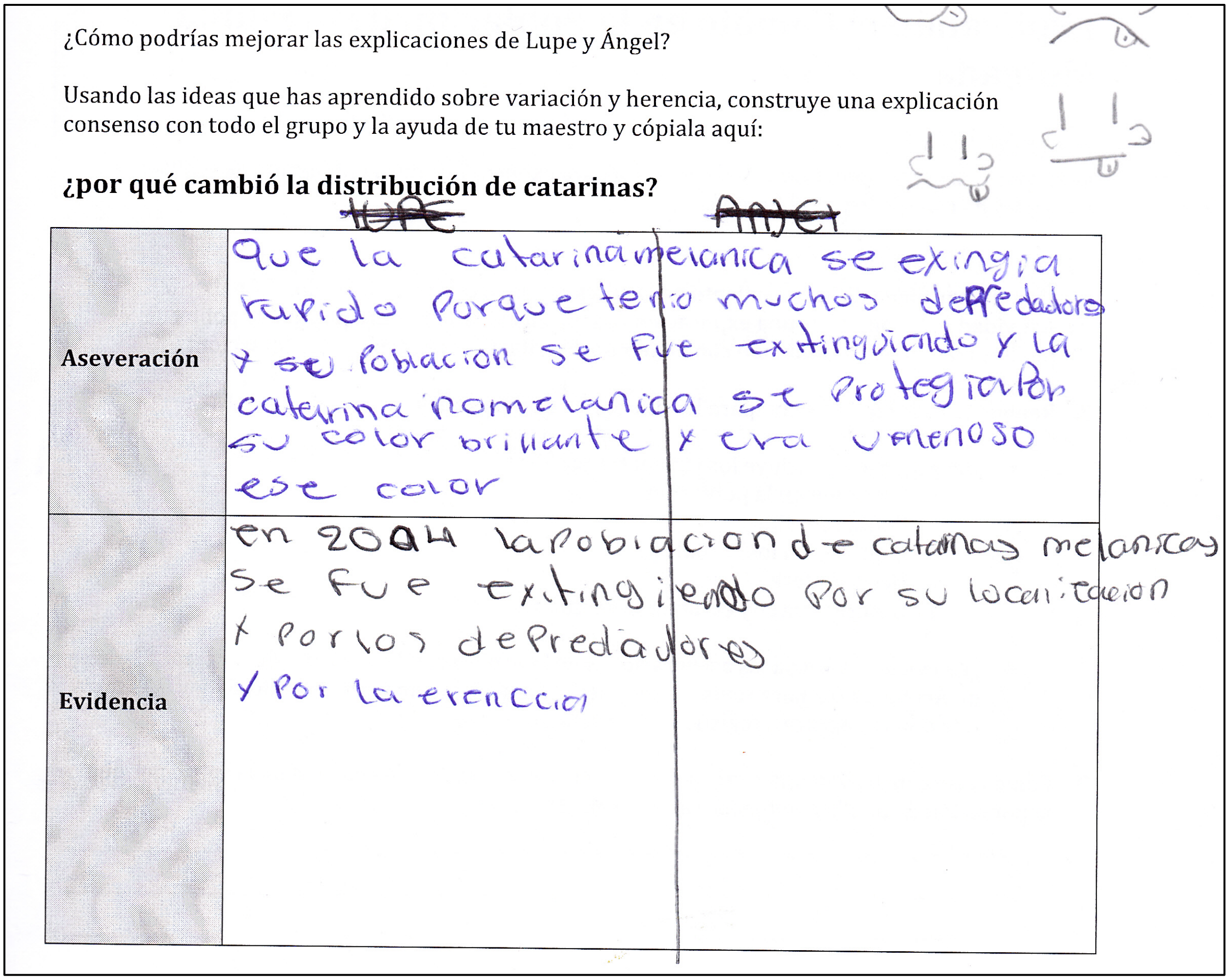
These dialogues reveal that students did not find it plausible that ladybugs could change color in response to an environmental pressure (need-based change). According to Evans, et.al. (2012, p. 193), a shift from "desire- or want-based reasoning in which reference is made to an intrinsic non-intentional process of change ("it needed to change") is associated with increasingly sophisticated evolutionary reasoning in children and in adults." This shift is further evidenced in the critiques students wrote of these desire- and need-based explanations, and in their revised explanations, as can be observed in a representative example below.



1. ¿Qué problemas tiene la explicación de Lupe?
Que los catarinas comencaron a reProducirce Por desicion Pero ellas no pueden decidir

2. ¿Qué problemas tiene la explicación de Ángel?
la aseveracionde anjel es "por eso se estan volviendo rojos" y ellas no se pueden cambiar decolor

[Translation: 1. What problems does Lupe's explanation have? Answer: *That ladybugs started to reproduce by own decision but they cannot decide*. 2. What problems does Angel's explanation have? Answer: *Angel's claim is "because they are turning red" and they cannot change color by themselves*.]



¿Cómo podrías mejorar las explicaciones de Lupe y Ángel?

Usando las ideas que has aprendido sobre variación y herencia, construye una explicación consenso con todo el grupo y la ayuda de tu maestro y cópiala aquí:

¿por qué cambió la distribución de catarinas?

	~~Lupe~~	~~Angel~~
Aseveración	Que la catarina melanica se extingia rapido porque tenia muchos depredadores y su poblacion se fue extinguiendo y la caterina nomelanica se protegia por su color brillante y era venenoso ese color	
Evidencia	en 2004 la poblacion de catarinas melanicas se fue extingiendo por su localizacion y por los depredadores y por la erencia	

[Translation: How can you improve Lupe's and Angel's explanations? Using the ideas that you have learned about variation and inheritance build a consensus explanation with your class and your teacher's help and write it down here.

Student's explanation:

Claim: *the melanic ladybug was experiencing extinction rapidly because it has many predators and its populations started to become extinct and the non-melanic ladybug got protected by its bright color and that color was poisonous.*

Evidence: *In 2004 the population of melanic ladybugs was becoming extinct because of its location, the predators, and the inheritance.*]

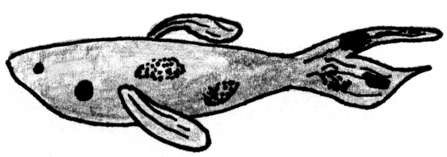
The directions for this activity include building a consensus explanation with the help of the teacher. However, because my goal was to evaluate whether students could critique the explanation and build a revised one based on what they had learned thus far, they were allowed to work in pairs to complete this activity and they had no further teacher input beyond what was offered in the dialogue excerpts above (e.g. questioning and prompting). As revealed in the representative student artifact above, most students included in their critiques that ladybugs cannot "decide" or "change" by themselves, demonstrating with that they do not engage in anthropomorphic reasoning or need-based transformational reasoning (Lamarckian). The new explanation constructed by this student reflects his knowledge of population change and although his attempt is to use causal mechanisms in his explanation, the struggle to explicate the association among body color, being poisonous, and predation (structure-function, and environmental pressure) using causal language is noticeable. As noted before, explaining this relation in completely causal terms (avoiding teleology) requires mastery of the nature of knowledge within a scientific discipline (Rector et al., 2012), in this case biology, which is not a reasonable expectation for adolescents in middle school (Catley et al., 2005).

Based on the results of this study I propose that a third step in the developmental learning progression on evolutionary reasoning proposed by Evans, et.al. (2012) should be a function-structure teleology. Although this is not how experts would reason, it seems not to interfere with learning causal mechanisms for biological phenomena and it can be a stepping stone towards a more refined and sophisticated understanding of biology that individuals might gain as they become enculturated in WSK and the discipline of biology.

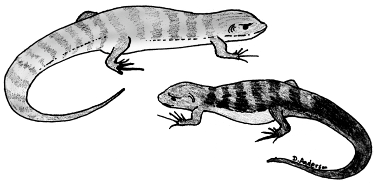
5.2.2.3. Students' performance in post-test items focused on population change and need-based inheritance.

A final source of evidence for my proposal that function-based teleology does not interfere with the learning of core concepts in evolutionary biology is students' performance on the items of the test focused on population change and need-based inheritance. The two items presented here were taken from the Conceptual Inventory of Natural Selection –CINS- (Anderson et al., 2002). Although these items include plausible teleological choices as distractors, more than half of the students chose the correct answer for these items. In fact, for those two items the average percent of correct response in this study is slightly higher than the average percent of correct response for the student who participated in the field trials of the original unit in the United States (Table 5.1).

Table 5.1. Nahua and US students' performance on CINS items that included teleological formulations as distractors.

<table>
<tr><th>Item from CINS</th><th>Nahua students Percent Correct</th><th>U.S. students percent correct</th></tr>
<tr><td rowspan="3">Venezuelan guppies

Guppies are small fish found in streams in Venezuela. Male guppies are brightly colored, with black, red, blue and bright reflective spots. In general, if fish are very brightly colored, they can be seen and consumed more easily by predators.

12. If the predators increase in the guppy's environment, which outcome is most likely?
a. The guppies will decrease in numbers over time. The proportion of more brightly colored guppies will decrease.
b. (T) The guppies will decrease in numbers over time, and then move to another habitat to escape the predators.
c. The guppies will decrease in numbers over time. The overall distribution of traits will stay about the same.
d. (T) The guppies will breed more offspring to make up for the lower rates of survival from the predators.</td><td>57.14%</td><td>54.78%</td></tr>
<tr><td colspan="2">Percent broken by choice</td></tr>
<tr><td>A*. 57.14%
B. 25.7%
C. 5.7%
D. 11.4%</td><td>A*. 54.78%
B. 21.66%
C. 16.35%
D. 6.37%</td></tr>
</table>

Canary Island Lizards  The Canary Islands are just west of the African continent. The islands gradually became colonized with life: plants, lizards, birds, etc. Three different species of lizards on the islands are similar to one species found in Africa. Scientists assume that the lizards traveled from Africa to the Canary Islands by floating on tree trunks washed out to sea.	62.85%	44.8%
	Percent broken by choice	
15. Which statement could describe how traits in lizards pass from one generation of lizards to the next generation? a. Lizards that learn to catch a particular type of insect will pass the new ability to offspring. b. Lizards that are able to hear, but have no survival advantage because of hearing, will eventually stop passing on the "hearing" trait. c. (T) Lizards with stronger claws that allow for catching certain insects have offspring whose claws gradually get even stronger during their lifetime. d. Lizards with a particular coloration and pattern are likely to pass the same trait on to offspring.	A. 17.14% B. 8.57% C. 11.42% D*. 62.85%	A. 18.26% B. 11.04% C. 24.63% D*. 44.80%

(T): Teleological formulation.

Overall, the average performance of Nahua students on the two items is similar to that of the larger U.S. sample, which suggests that the contextualization principles introduced to the unit (principles 1 and 2) had a positive impact on students' learning of content knowledge. The fact that for the two items, but especially for the second one (item #15), the performance of Nahua students is higher than that of the US sample is more difficult to interpret. The difficulty arises because in contrast to this dissertation study, the U.S. data was collected from a wide range of schools in 25 classrooms with no direct contact with the IQWST team other than the one-week of professional development, and a lower rate of unit completion (73% to 100%), compared to the 100% achieved in this study. Among the 25 classrooms wide range of pedagogical approaches were adopted in completing that unit, which likely influenced students' performance. In fact, preliminary data from item analysis shows high variability in students' performance across the 25 classrooms (Reiser, 2013. Personal communication.) Given the different approaches, a direct comparison is difficult to establish (in the case of this study, the fidelity of implementation was high and there were two classrooms only), but taking into account that US students routinely take multiple-choice tests while the students in this study have limited test-taking skills, and that the U.S. students experienced two other Biology IQWST units in prior years, while this was the first time for Nahua students, it is noteworthy that more than half of the sample chose the correct answer even when plausible teleological choices were available. Moreover, the pre-test score for these two items was lower for Nahua students than for U.S. students, indicating an even larger learning gain motivated by learning with the contextualized unit.

Table 5.2. Frequency of correct response for items 12 and 15 in the Pre Test (Nahua vs. U.S. students)

Item	Pre Test Score Nahua Students	Pre Test Score U.S. Students
12	36.9%	42.37%
15	23.07%	37.92%

These results suggest that adding culturally based narratives with marked teleo-functional components to the unit supports students' learning of WSK, potentially facilitating their access and understanding of that knowledge and further supporting the idea that the observed teleological bias that students presented did not interfere with their meaning making of natural selection as a causal process, even when they still apply teleo-functional reasoning in their explanations of population change and inheritance.

Overall, the results of the teleology interview combined with students' artifacts and pre/post test scores suggest that using students' culturally-based narrative as a gateway to WSK concepts and having students critique teleological explanations has the benefit of targeting instruction to specific potential cognitive biases, while also providing information about students' progress in a more fine grained manner as compared to prior studies (Casler & Kelemen, 2008; Kelemen et al., 2012; Kelemen, 1999, 2012; Lombrozo et al., 2007). These results agree with proposals of other researchers that helping students develop explanations about evolutionary phenomena has the potential to also improve students' content knowledge (Beardsley, Bloom, & Wise, 2012; Sandoval & Reiser, 2004). Using scaffolds to build scientific explanations and using the Galapagos finches website was part of the original IQWST unit, which was supplemented with the contextualization principles 1 and 2 in this study (critiquing essentialist or teleological explanations in a scaffolded manner) seems a promising approach for supporting students in overcoming desire-based and need-base teleological biases that interfere with evolutionary reasoning. Principles 1 and 2 also allow taking advantage of students' culturally based teleo-functional biases as resources for learning of WSK concepts such as the relationship between structure and function, inheritance, and natural selection.

5.3. Effects of the unit on students' essentialist reasoning

Contextualization principle 3 was designed to address the essentialist patterns of reasoning that 7th grade students exhibited when thinking about animals and plants. Specifically, this principle is based on using students' culturally based knowledge of the variability of traits in local plants as a context to understand how external properties are linked to internal properties (relationship phenotype - genotype).

This feature was designed to use students' traditional knowledge about variability of external properties of plants and animals (phenotype) as a resource to facilitate their understanding of western science ideas such as genotype, genetic diversity, and genetic pool. My hypotheses were that after learning with the contextualized unit that included this feature to specifically address essentialist reasoning, students would 1) exhibit a lower frequency of essentialist reasoning in the essentialism interview, and 2) report a significant gain in the two items assessing within-species variation from pre to post-test. These hypotheses were tested in the following manner:

- Changes in students' recognition of actual variability were tested by conducting two repeated-measures ANOVA with pre and post-test scores as the between subjects factor and domain (plant or animal) and property (internal, external, behavioral) as the within subjects factor subject.
- Changes in students' recognition of potential variability were tested by conducting two repeated-measures ANOVA as described above.
- Matched t-tests were conducted for the pre and post scores for the items targeting content related to within-species variation.

The essentialism interview was further modified from the results of the pre-contextualization stage so that students would find the statements more plausible. The two main modifications focused on these two aspects: 1) the question assessing variability of external features in pigs originally asked whether "all pigs had snouts." During the pre-contextualization interviews students and adults thought it would be impossible to find a pig without a snout so this question was changes to reflect variation in the type of snout to say "do all pigs have rounded snouts?" 2) Similarly, students and adults found it implausible that a hen would be completely devoid of feathers, so that the original question "do all hens have feathers" was modified to say, "do all hens have feathers all over the body"?

The essentialism interview and the content test were with the same participants and in the same timeframe as the teleology interview (see section 5.2 for detail).

5.3.1. Results

Contrary to my first hypothesis, students did not show a significant change in the frequency of essentialist answers for actual variability or potential variability. There was no significant pre/post effect for the domain x property interaction for either time point for actual variability (for behavioral, internal, and external animal properties $F(2,138) = 0.05$, $p = .67$, $\eta^2_p = .94$, or for internal and external properties of animals vs. plants $F(1,69) = 1.25$, $p = .266$, $\eta^2_p = .018$) or potential variability (for behavioral, internal, and external animal properties $F(2,138) = 1.14$, $p = .32$, $\eta^2_p = .016$, or for internal and external properties of animals vs. plants $F(1,69) = 0.44$, $p = .51$, $\eta^2_p = .006$).

Overall, students were more likely to admit actual variability for behavioral properties of animals both in the pre and post interviews than for external and internal properties of animals and plants (fig. 5.8). It is interesting that although not significant, there is a slight decrease in the frequency of properties that students judged actually variable in the post-test.

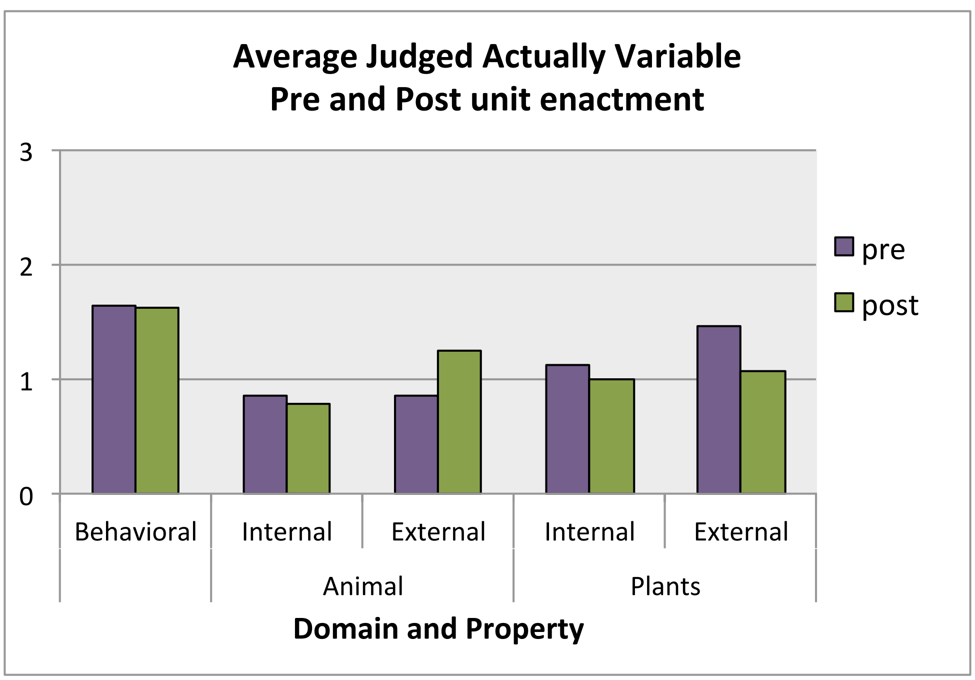


Figure 5.8. Responses judged actually variable across domains and properties.

Similarly, there was no significant pre/post effect for potential variability but there is a consistent trend of decreased judgment of potential variability across properties and domains in the post-test (Fig. 5.9).

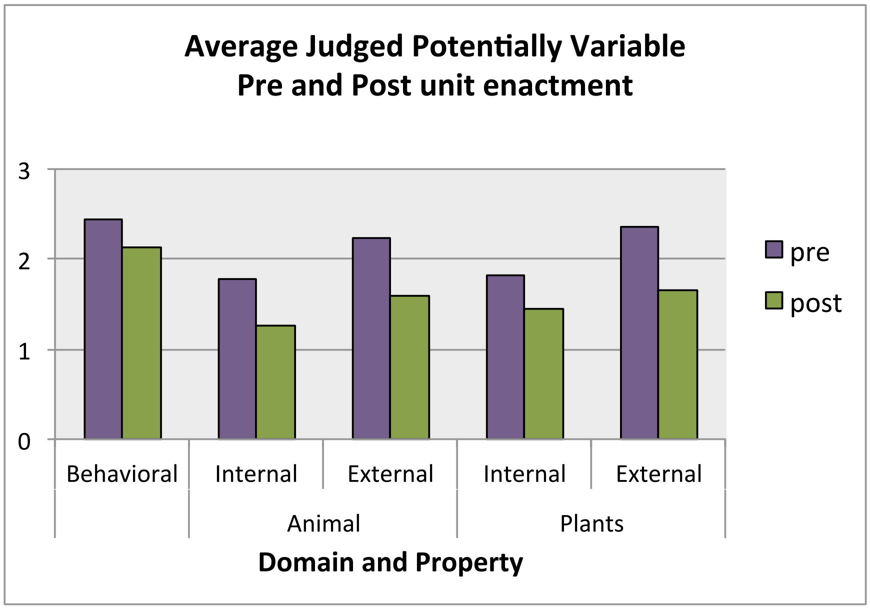


Figure 5.9. Responses judged potentially variable across domains and properties.

In contrast with the first hypothesis, the second hypothesis was proved correct by the t-test. After working through the contextualized unit students were significantly more successful at not selecting the distractors designed to elicit essentialist reasoning or not-acceptance of within species variation. For the first item (#4) addressing content related to essentialist reasoning, there was a statistically significant increase in the frequency of correct response ($M1=0.31$, $M2=0.65$; $t=-2.8$, $p<0.01$). The same significant pattern was observed for item 11 ($M1=0.45$, $M2=0.66$; $t=-2.5$, $p<0.01$).

5.3.2. Discussion

Although the results of the essentialism interview did not support the hypothesis that learning with this 11-week contextualized unit would decrease students' essentialist tendencies, these results are not surprising. An essentialist reasoning bias allows for successful inference and categorization based on observed real world regularities, rendering it a useful reasoning pattern to understand and explain the world around us (Gelman, 2003). A pattern that has served students well for their whole lives is difficult to alter in just a few weeks, even with well-designed instruction. However, the challenge with students exhibiting this type of thinking when it comes to learning science is that strict essentialization of natural categories impedes appreciation of within-species variability, which in turn hinders an accurate understanding of biological processes such as natural selection (Evans & Rosengren, 2012; Shtulman & Schulz, 2008; Shtulman, 2006). In the case of the Nahua students participating in this study, they admitted within-species potential variability at a high frequency for behavioral properties of animals and external properties of plants (fig. 5.9), something they have rich culturally-based knowledge about, and about half of the time admitted variability in internal properties (fig. 5.9), for which they have less knowledge, which is consistent with the literature (Shtulman & Schulz, 2008). One way to interpret these results is that students seem to exhibit a less strict essentialist bias and that the more knowledge they have about the properties of a natural kind the more they will be willing to admit variability within that category.

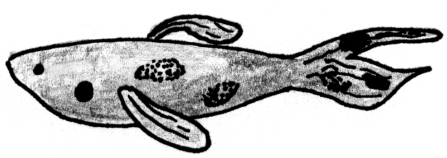
A less strict essentialist bias may change in two directions: either it will become truly flexible/contextual or will be overcome completely. Both of these scenarios seem implausible. A more nuanced and contextual use of essentialist reasoning, depending on the process to explain (e.g. taxonomy), may come with years of education in a scientific discipline, which middle school students do not have. On the other hand, overcoming essentialism completely seems beyond the realm of human possibilities. According to Gelman (2003): "*The cognitive capacities that give rise to essentialism are a varied assortment of abilities that emerged for other purposes but inevitably converge in essentialism. In that sense, essentialism is something we do neither because it is "good" for survival, nor because it is "bad" for people who are manipulated by essentialist rhetoric.*

Essentialism is something that we as humans cannot help to do." Taking into account that essentialism is so deeply engrained in the human mind, it would not be reasonable to speak of "overcoming" this bias nor should science educators harbor such expectations when teaching topics such as natural selection. The goal of teaching should be to achieve a flexible and highly contextual use of essentialist reasoning that includes a metacognitive component of what essentialism is and when and how one is applying this type of reasoning. Instruction based on this approach may be fruitful for supporting students into successfully applying or avoid applying essentialist reasoning in the context of learning Western science. However, that was not the approach I used to contextualize the unit.

The approach I used in the unit, which took advantage of students' rich cultural knowledge of external properties of plants to help them recognize within-species variability across domains (plants and animals), may be successful in populations where students exhibit a much stricter essentialist bias. In those cases, instruction focused on highlighting within-species variability may produce significant changes in the essentialist bias, especially when measured with the type of interview I used in this study.

Because the identity of individuals remains the same for students despite outward variation, Shtulman & Schulz (2008) procedure may not be highly sensitive to differences between the strict and flexible essentialism that students may develop when learning science (the items are not phrased in terms of degrees of variation but in terms of having or not having a certain feature). It may be that students recognize within species variation in pigs, but still insist that "all pigs have strong bones", privileging identity over outward variation. If this is the case, the results presented here make sense, because students would exhibit no change in essentialist bias, as measured with the Shtulman & Schulz (2008) procedure, but would exhibit score changes in questions specifically asking about the distribution of a trait in a population, as is the case here (table 5.3).

Table 5.3. Nahua and US students' performance on test items that included essentialist formulations as distractors.

Item from Test	Nahua students Percent Correct	U.S. students percent correct
4. Dogs have a more sensitive sense of smell than humans. Does heredity help explain this? a. (E)Yes. All dogs are the same species, so they will all have exactly the same traits. b. Yes. The genes that lead to a better sense of smell are present in all dogs, so offspring from any combination of dogs will also have this trait. c. No. Dogs belong to different species than humans, so differences between dogs and humans are not due to heredity. d. No. The dog's sense of smell can't be explained by heredity, because there are so many different kinds of dogs.	65.71%	53.05%
	Percent broken by choice	
	A. 5.71% B*. 65.71% C. 17.14% D. 11.4%	A. 5.73% B*. 53.05% C. 25.9% D. 11.68%
Venezuelan guppies  Guppies are small fish found in streams in Venezuela. Male guppies are brightly colored, with black, red, blue and bright reflective spots. In general, if fish are very brightly colored, they can be seen and consumed more easily by predators. 11. A population of guppies consists of hundreds of guppies of the same species. Which statement best describes the guppies in the population? a. (E)The guppies share all of the same characteristics and are identical to each other. b. The guppies share all of the essential characteristics of the species; the minor variations they have don't affect survival. c. (E)The guppies are all identical on the inside, but have many differences in appearance. d. The guppies share many essential characteristics, but also vary in many features.	65.71%	44.8%
	Percent broken by choice	
	A. 11.42% B. 2.85% C. 20% D*. 65.71%	A. 13.8% B. 23.99% C. 16.56% D*. 44.80%

(E): Essentialist formulation.

Similar to the items including teleological distractors presented in the prior section, Nahua students in this study scored higher than U.S. students on items including essentialist formulations as distractors. Taking into account that this was the first contact of Nahua students with an IQWST unit, while most of the US students had this unit as the third one in the IQWST sequence, their performance on these items is worth noting. These scores may suggest that using students' knowledge of the phenotypic variation of familiar plants –such as corn- as core examples in the unit is a productive avenue for students to recognize the variation of a trait within a population, which is a concept key to understand natural selection. However, only recognizing within-species variation and designing instruction tailored to this purpose without an explicit discussion of what essentialism is and how it looks when in the context of explaining biological processes reinforce (or even augment) a generalized essentialist bias. More specifically, when students learn about DNA, chromosomes, and internal mechanisms of inheritance that are invisible to them, those concepts help them "name" a causal essence for biological categories (species), and therefore those newly learned concepts are mapped onto an already existing essentialist framework in place for internal properties of natural kinds. If this is the case, the slight increase in essentialist reasoning across domains and properties observed in figure 5.4 becomes easier to understand. After having learned concepts related to biological inheritance (without an idea of what essentialism is) students invoked DNA as evidence or proof of an underlying essence common to all members of a species, even when the members of the species varied phenotypically, and even when knowing that the environment influences gene expression. These results point to a need to conduct research in biology education exploring the effects of metacognitive awareness of essentialism in the accurate understanding of natural selection and evolution.

This metacognitive awareness of essentialism might be one characteristic of the sophistication in reasoning exhibited by biologists. Essentialist reasoning is profitable in the domain of biology where specific disciplinary areas such as taxonomy and genetics make use of it to establish categories and explain processes based on the idea that non-obvious features cause outward similarities (e.g. phylogenetic trees or the relationship genotype – phenotype). This type of reasoning does not prevent taxonomists and geneticists from understanding and appreciating the role of within-species variation in biological processes, because as part of their scientific training and content knowledge of their discipline their essentialist bias develops into a flexible and contextual bias that is applied when appropriate. This flexibility and judgment as to when it is appropriate to apply essentialist reasoning may be one of the markers of highly sophisticated scientific reasoning. Therefore, as with teleological reasoning, it would not be developmentally appropriate to expect the same performance from middle school students after 11 weeks of instruction. To achieve this level of competence it would be necessary to design scaffolds to support students in progressively reaching that level of understanding.

Based on this analysis I can conclude that although students exhibited learning gains in content related to recognizing within species variation, they showed a tendency to conceive of species in a reductionist manner, using DNA and the biological mechanism of inheritance they learned as justification for species identity. In this sense, principle 3 was unsuccessful in helping students to achieve a more accurate understanding of natural selection and that for future enactment of this unit changes should be introduced that explicitly address what essentialism and biological determinism (reductionist understanding of species) are. Such changes would be highly compatible with culturally relevant pedagogy, because it would facilitate addressing topics pertaining to social justice and draw connection to other subjects (e.g. social studies), thus increasing the relevance of learning biology for students while helping them achieve a more sophisticated understanding of natural selection.

5.4. Summary

The literature reports teleology and essentialism as biases that interfere with learning of natural selection and evolution (Gregory, 2009; Shtulman & Schulz, 2008; Shtulman, 2006; Wilkins, 2013)This has led to the recommendation that students receive instruction and support to overcome those reasoning patterns in order to learn the concept of natural selection. What these studies fail to take into account, however, is that “teleology” and “essentialism” are not static and monolithic biases. Rather they vary in degree and may also manifest in different ways from one disciplinary domain to another or to daily life. In this context, the main contribution of this study for science education is that those deeply engrained reasoning biases may not need to be overcome in order to successfully achieve an accurate understanding of natural selection and biological evolution.

In the case of teleology, function-based teleology seems not to interfere with the learning of inheritance and natural selection, while it may facilitate understanding one of the main structuring principles of biology: the relationship between structure and function. In this regard, one more contribution of this study is that it highlights the fact that students from non-Western cultures –and potentially from Western agricultural communities- do exhibit function-based teleological reasoning patterns that become resources in the context of learning Western science in manners that do not conflict with their own culturally-based views of the world. This is an important finding because, especially in contexts such as the Mexican public educational system where indigenous students are viewed as having deficits. Importantly, this study provides research-based evidence that this population of students come to the classrooms with resources (and advantages over non-minority students) to learn science, which may have positive effects on the type and quality of instruction teachers engage in, and may also decrease the discrimination indigenous students experience in the science classroom.

In the case of essentialism, the results of this study lead to a noteworthy conclusion for the field of science education. Even when students successfully learn about within-species variation and distribution of traits within a population, those ideas may map onto students' essentialist construal of species increasing an essentialist bias or leading to reductionist understandings of biological species. Therefore, instruction needs to be designed to go beyond teaching students to appreciate and understand the role of within-species variation to a scaffolding them in progressively develop a more flexible and contextual use of essentialism when appropriate. As noted before, one of the advantages of including explicit instruction on essentialism in biology classes is its compatibility with social justice topics, facilitating students use of science knowledge to be critical of ideas such as biological determinism or essentialization of social categories.

CHAPTER 6: EFFECT OF CONTEXTUALIZED CURRICULUM ON HOW STUDENTS CROSS BORDERS BETWEEN WESTERN SCIENCE AND NAHUA CULTURE.

6.1. Introduction

In the prior chapters I described how I designed the contextualization principles introduced to the IQWST unit, followed by a chapter reporting the effect of those principles in the students' teleological and essentialist reasoning patterns. In this chapter I continue describing the effects of the contextualization principles I designed, but I focus specifically on how students did or did not crossed borders between their own traditional knowledge and Western science knowledge. The evidence for border crossing that I will present in this chapter comes from fifty-three student interviews (25 mid-point interviews, 28 final interviews), eight hundred and forty worksheets from the students' notebooks, and my field notes collected during the enactment of the unit in the two classrooms (see methods chapter for a detailed description on sample selection). I will use excerpts from classroom dialogues when necessary, to help better illustrate a claim derived from the analysis, but classroom dialogues were not included in the analysis because of the quality of recordings were not consistent throughout the enactment of the unit.

Because this chapter focuses on border crossing I will briefly expand here on the border crossing ideas presented in Chapter 3, to clarify, for the reader, the key conceptual points on which I based the analysis presented in this chapter. Border crossing is defined, in this dissertation, as the movement from one interpretative frame rooted in one culture to a different frame rooted in another culture, that occurs in response to cues in the social environment (Aikenhead, 2001; Hong, Morris, Chiu, & Benet-Martinez, 2000). This definition of border crossing does not negate the hybridity and overlapping that can exist between different epistemologies or that can arise when individuals fluidly navigate cultures. In this sense, the critique of authors such as Carter (2004) that the border crossing approach works to maintain Western science and Indigenous cultures apart, "othering" the traditional knowledge and making it inferior, does not hold valid for the border crossing approach presented in this dissertation. Even less so because border crossing was operationalized in the design of the contextualization principles with a critical approach, making sure that learning Western science would not silence students or ask them to abandon their critical voices and lived realities (Kinloch, 2012). On the contrary, the approach used here encouraged students to use their traditional knowledge and lived experiences within the science classroom as valuable tools for learning, thus questioning the devaluation of Nahua knowledge by the Mexican educational system effected in part by conferring higher status and exclusive validity to Western science. I used this approach because it is compatible with the principles of Culturally Relevant Pedagogy (see Chapter 2). By portraying Western science as one way of knowing that does not require students to give up their identities it has the potential to facilitate and motivate learning (Bang & Medin, 2010). Note that I am explicitly referring to Western science as one way of knowing because understanding Western science this way allows us to avoid hierarchical categorizations in which other ways of knowing (e.g. Nahua traditional knowledge) become delegitimized. By legitimizing students' traditional knowledge throughout the contextualized unit I was expecting to motivate students to become engaged with the complex task of navigating multiple ways of knowing as a means to facilitate students' access to Western science (i.e. contents and practices) and thus observing learning gains in the contents taught in the unit.

Although these were the my intentions when conceptualizing the contextualization principles, it was only through students' artifacts and by listening to their learning experiences I came to realize that border crossing through the navigation of two ways of knowing (Nahua and WSK) was actually experienced by most students, as I will document in this chapter. I will also document those cases in which students struggled to make sense of the contents and practices taught in the science class, thus not experiencing smooth border crossing between cultures. As described in Chapter 5, students exhibited significant learning gains, as measured by the multiple choice test. Therefore, I can conclude that the border crossing experience did not hinder students' learning of science concepts but most likely motivated and aided the learning process, as I will describe in the rest of this chapter.

6.2. Results

Once the coding of the data corpus was complete, I created a cluster map as a useful tool to explore the relationships between categories. The map provided an overall idea of the experiences of the students when crossing borders between WSK and Nahua knowledge during the enactment of the contextualized IQWST unit.

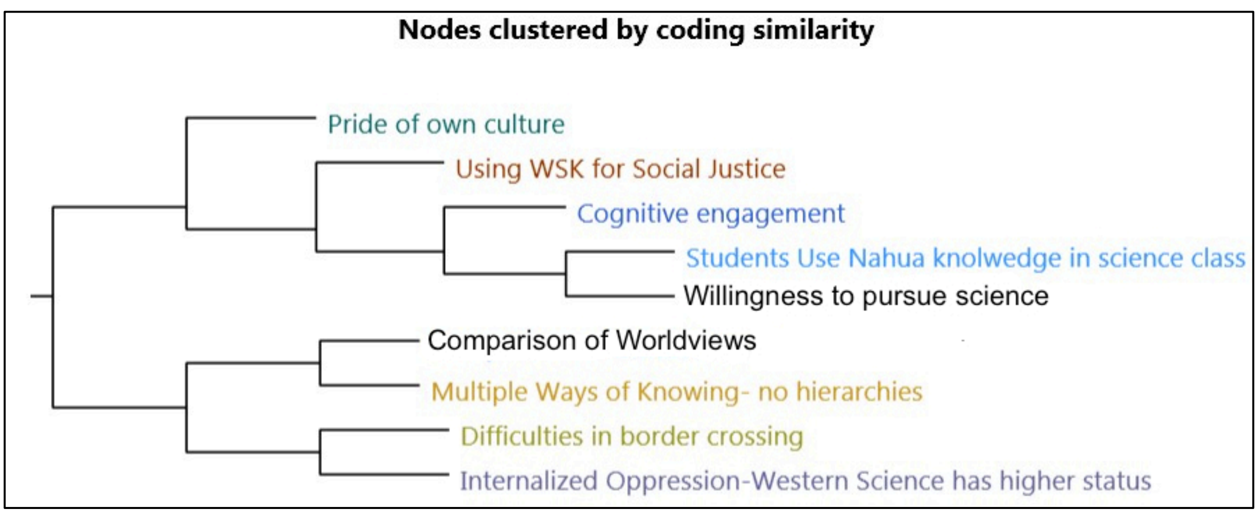


Figure 6.1. Cluster map of coding categories.

In figure 6.1 the cluster map shows the coding categories grouped according to their similarity using Jaccards' coefficient (see Chapter 3 for detail). This cluster map suggests that by comparing worldviews (Nahua and WSK) students became proficient in navigating Nahua and Western science ways of knowing without hierarchizing them. In contrast, students whose texts and interviews showed a belief that their own culture was inferior to that of Western science (internalized oppression) demonstrated difficulties in the border crossing between cultures. The cluster map also suggests that students who demonstrated pride in their own culture used their Western science knowledge for social justice (e.g. against discrimination based on biological basis), were cognitively engaged, used their Nahua knowledge in class, and ultimately stated they would like to pursue science when they grow up.

A more detailed way of making sense of the whole data corpus is by looking at the frequency of coding for each category. To understand the relative importance of the above-mentioned patterns in students' experiences of border crossing, we must look at the frequency of coding for each category (see Table 6.1).

Table 6.1. Frequency of coding for each category in the data corpus

Name	Sources*	References**
Multiple Ways of Knowing- no hierarchies	**100**	**108**
Using WSK for Social Justice	**92**	**94**
Comparison of worldviews	**88**	**88**
Willingness to pursue science	72	74
Students Use Nahua knowledge in science class	60	72
Pride of own culture	48	48
Cognitive engagement	38	46
Difficulties in border crossing	17	21
Internalized Oppression-Western Science has higher status	8	8

* This analysis is based on four data sources: transcripts of interviews, students' worksheets, field notes from classroom observation

** References mean the total frequency of a given code across data sources.

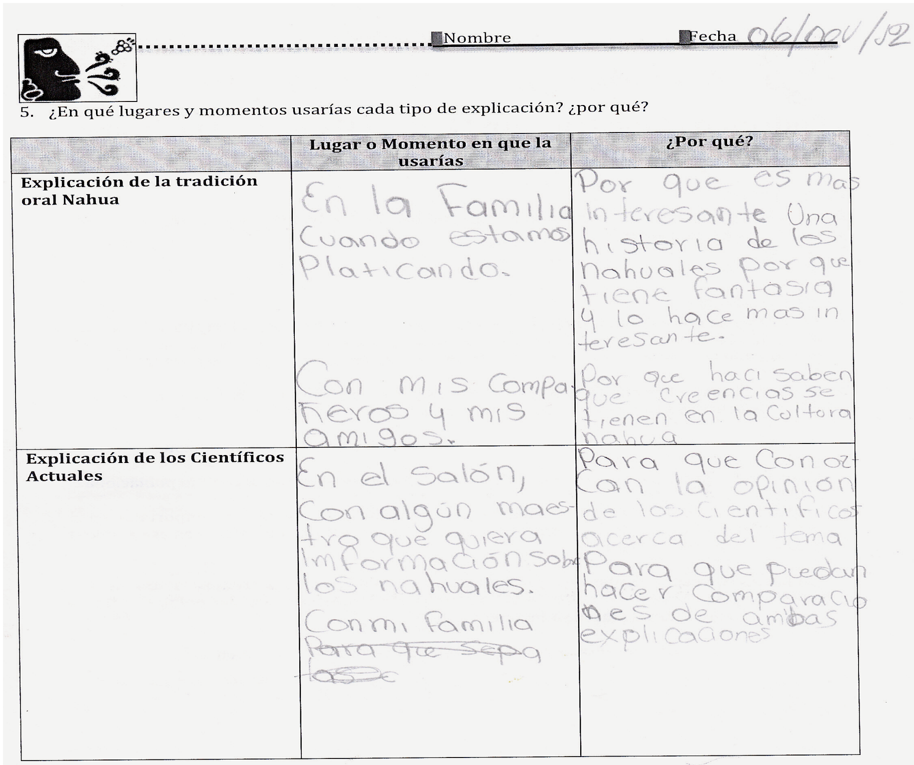
As Table 6.1 shows, the most common categories in the data corpus were "multiple ways of knowing –no hierarchies", followed by "using Western science knowledge for social justice", and "comparison of worldviews." These first and third categories were grouped together in the cluster map and are conceptually related. For example, comparing worldviews can be a path towards understanding that there are multiple, not competing ways of knowing; therefore, they will be discussed jointly in the next section (6.3.1). The second most referenced category, "using WSK for social justice" will be discussed in section 6.3.2 along with the also frequent categories "students Use Nahua knowledge in science class", "pride on own culture", "cognitive engagement", and "willingness to pursue science," because they were grouped together in the exploratory cluster map. Additionally, my field notes and observations support the idea that the moments when most students were cognitively engaged were those in which they used their traditional knowledge, discussed topics such as discrimination, or when elements of indigenous cultures were highlighted as valuable. Finally, in section 6.3.3 I will discuss the difficulties experienced by some students in in border crossing and how it is related to internalized oppression (e.g. believing science has higher status or believing that their ethnicity conflicts with pursuing Western science). Although these two categories have a low frequency of reference compared to other categories, it is important to analyze them to better understand the range of experiences students have when learning Western science in a culturally relevant manner.

6.3. Discussion

6.3.1. Comparing worldviews: a path towards accessing multiple ways of knowing

In chapter 4 when describing principle 5 (Incorporating traditional Nahua oral narratives to legitimize students' traditional knowledge in the context of the science classroom), I presented the example of students watching a video [Principle 8] about a Nahuales story was told in Nahuatl language [principle 6]. In this activity students were supported in analyzing the story from the points of view of Western science and the Nahua culture. This activity and others that presented Nahua narratives familiar to students proved to be opportunities for them to see two types of discourses side by side, think about the value and utility of each discourse, and realize they can use both in different contexts. As a result, most students started to see Western science and their own culture as different ways to approach knowledge that they could use in different contexts. These reflective processes were scaffolded with comparative charts and prompts included in the students' worksheets that supported comparison but discouraged hierarchization. Most students achieved some degree of border crossing between Nahua culture and Western science, although different students made sense of these comparisons of worldviews differently. For example, Laura was a smooth border crosser (fig 6.2), placing both Nahua knowledge and Western science knowledge in the contexts of community/family and school. In the worksheet below (fig. 6.2), Laura assigns worth to each type of knowledge by describing the different purpose those types of knowledge have in different contexts with different groups of people.

It is interesting to see her reasoning for her family to use WSK. She envisions them engaging in the same activity she does at science class: making comparisons between explanations coming from different worldviews. This may indicate: a) willingness to use WSK in her everyday community life, and b) signaling that using WSK makes sense for her when her family can also use it in the ways she has learned to do it at school. Laura does this while still making it explicit that she is proud of her traditional knowledge and enjoys traditional narratives. The fact that Laura can understand science as relevant for her family and community will likely have a positive effect in her engagement in school science throughout her school life (Aikenhead, 2006; Bang & Medin, 2010) and constitutes a good example of border crossing.



Nombre Fecha 06/nov/12

5. ¿En qué lugares y momentos usarías cada tipo de explicación? ¿por qué?

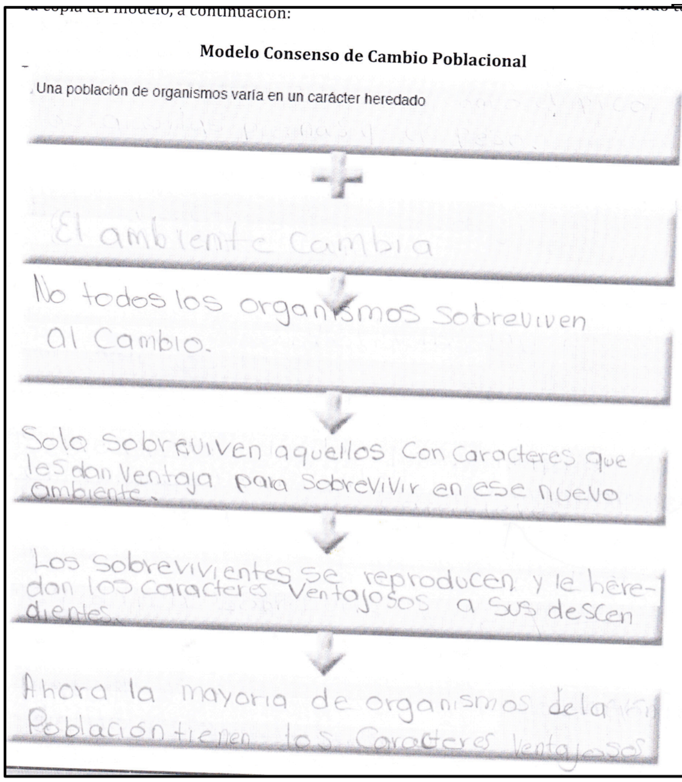
	Lugar o Momento en que la usarías	¿Por qué?
Explicación de la tradición oral Nahua	En la Familia Cuando estamos Platicando. Con mis Compañeros y mis amigos.	Por que es mas interesante Una historia de los nahuales por que tiene fantasia y lo hace mas interesante. Por que haci saben que creencias se tienen en la Coltura nahua
Explicación de los Científicos Actuales	En el Salón, Con algún maestro que quiera información sobre los nahuales. Con mi Familia ~~Para que sepa las e~~	Para que Conozcan la opinion de los Cientificos acerca del tema Para que puedan hacer Comparaciones de ambas explicaciones

5. In what places and moments would you use each type of explanation? Why?

	Place or moment where you would use it	Why?
Explanation from the Nahua oral tradition	In the family when we are talking With my peers and friends	Because a story about nahuales is more interesting, because it has fantasy and that makes it more interesting. Because that way they know what beliefs the Nahua culture has.
Explanation from current scientists	In the classroom with any teacher who wants information about nahuales. With my family ~~so the know the e~~	So that they know scientists' opinion about this topic. So that they can make comparisons of the two explanations.

Figure 6.2. Laura's worksheet after analyzing how would the Nahua tradition and Western science explain a different-looking dog.

Laura's experience of border crossing was successful because she was able to hold the two points of view throughout the enactment of the unit, showing cognitive engagement and succeeding at completing challenging tasks such as pedigrees of different traits in a family or the model of population change (fig 6.3. below).



Consensus Model of Population Change

A population of organisms varies in an inherited trait
|
|
The environment changes
|
|
Not all organisms survive the change
|
|
Only can survive those with traits that give them advantage to survive in that new environment.
|
|
Survivors reproduce and inherit advantageous traits to their offspring
|

Figure 6.3. Laura's model of population change

However, for an even smoother border crossing a student should also be able to place Nahua knowledge in the context of school and show openness to opportunities to share it with teachers and scientists (Costa, 1995). This type of border crossing is exemplified in Carmen's experience (Fig. 6.4). Carmen understood Western science as an exercise of studying and understanding the world, therefore scientists would benefit from understanding her culture and other cultures in the world. She also sees WSK as useful to her community in a way that is complementary to what they already know and have known for generations. This understanding of WSK as complementary to her own knowledge is evidence that she is not hierarchizing those types of knowledge but discovering ways to use them in varied contexts, thus successfully border crossing between different ways of knowing (Snively & Corsiglia, 2005).

4. ¿ Piensas que el conocimiento propio de tu cultura puede ayudar a los científicos a entender mejor el mundo? ¿Por qué?

Si, porque es parte de su investigación y aprender la cultura cada pueblo del mundo

5. De acuerdo con todo lo que has aprendido hasta ahora, ¿ Piensas que el conocimiento científico puede ayudar a tu comunidad a entender mejor el mundo? ¿Por qué?

Si, porqué ya tienen una mejor idea para que sirven sus remedios que ellos hacían desde la antigüedad

4. Do you think that your culture's knowledge can help scientists better understand the world? Why?

Yes, because it is part of their research and they learn the culture of each nation in the world.

5. According to what you have learned so far, do you think that the scientific knowledge can help your community to better understand the world? Why?

Yes, because they would have a better idea of what are their ancient medicines for.

Figure 6.4. Carmen's worksheet after discussing how Aztecs and Nahuas have traditionally used honey for healing with success

This experience of smooth border crossing was not uncommon among students after engaging in activities designed following principles 4, 5, and 6. For example, most students were able to think about phenomena such as the healing properties of chocolate or the biodiversity of corn from the points of view of Nahua traditions and WSK without experiencing conflict. In another example, students learned about PTC (phenylthiocarbamide) and how only some people had the inherited ability to taste this bitter compound. Students were given the opportunity to find out who was sensitive to

PTC with the PTC stripes and then observe their reactions to unsweetened coffee and bitter chocolate diluted in water. The consumption of these beverages is widespread in the students' communities but they are drunk sweetened. Students' curiosity was piqued so that they asked their parents why they always sweetened those beverages and they carefully read the story about how ancients Aztecs used chocolate. The discussion in class was focused on how Nahuas thought unsweetened chocolate would give you a stomachache therefore, people would dislike the drink and prefer it sweetened. However, scientists would say that people who reject unsweetened chocolate might have inherited the trait of being sensitive to PTC.

Teacher: what have you heard about chocolate

Arisai: Aztecs said it made people happy

Daniel: doctors say it gives you energy and contains proteins

Teacher: what else?

César: it is medicine, because it is a hot plant

Imanol: yes, like tapón.

Teacher: yes, sometimes we feel much better after drinking chocolate; many of us have experienced that. Who told you that César?

César: I learned that at home

Teacher: did you hear that from your parents?

César: no

Juanito: from your peers!

Teacher: from your parent's friends?

César: no

Teacher: I mean, what you said is right, you will see in a few minutes, I just want to know how you learned it.

César: my brother's mother in law told me.

Juanito: teacher, teacher, Jesús wants to participate

Jesús: chocolate keeps your body warm

Teacher: who told you that?

Jesús: my grandmother, my mom and my dad.

[Four more students share similar ideas with the class and report having learned from family members. The teacher writes the ideas in the whiteboard while students share]

Teacher: what is the next question in the worksheet? What have you heard about chocolate from your family and community? Well, we have a good list here already [she reads the list out loud.] So after all, we all have learned similar ideas at home to those in the reading [the reading about how ancient Aztecs used chocolate], so go ahead and work in your worksheet.

[10 minute after]

Teacher: ok, what's next? How do you think that scientist would explain that Aztecs and Mayas rejected bitter chocolate?

[Students talk among animatedly them until the teacher ask them to participate one by one so she can better understand what they are saying]

Teacher: ok, let's start with this team

Imanol: scientist would explain that Aztecs did not drink it [bitter chocolate] because of the taste.

Teacher: what else? Ok, let's get together in teams and we are going to think as scientists now. Let's imagine we are scientists and think about it. Two more minutes. Let's work!

Teacher: I will give you a hint. Do you remember the video we saw?

Daniel: about PTC

Teacher: that's right, what did we learn?

Alejandro: it is bitter

Laura: that the ability to taste PTC is inherited

Teacher: ok, very good. And that ability depends of…?

Silvana: of the traits

Ronaldo: some people can feel that flavor and others can't

Imanol: some people have traits that allow them to have the PTC strip in their mouth and not feeling it is bitter.

[Three more students share similar ideas]

Teacher: ok, we are close to the answer to the question "how would scientist explain that Aztecs and Mayas rejected bitter chocolate", so take a few minutes and work in your worksheet.

[5 minutes after]

Teacher: each team is going to share now

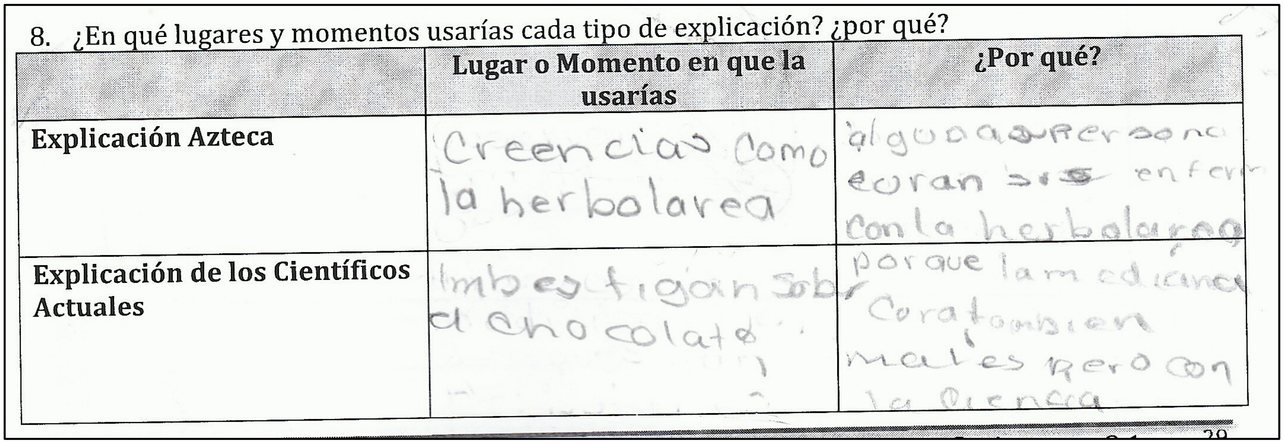
Alejandro: maybe Aztecs had a trait for being sensitive to bitter flavors

Daniel: some Aztecs were sensitive to PTC so they disliked bitter chocolate

Sergio: because they had traits that made them sensitive to the bitter flavor of chocolate.

Teacher: good, let's work on the next question.

In this whole class discussion it can be seen how the teacher prompted students to think about chocolate's bitterness from the point of view of Nahua knowledge and then from the point of view of Western science, but without any hint of judgment or "correctness" so that neither of those types of knowledge was placed above the other. During those class discussions, readings, and videos [Principle 8] students were able to practice taking on different perspectives when thinking about a situation or a phenomenon, thus becoming more and more proficient at border crossing. After the class discussion, shown above, students were asked to work individually on a chart comparing when and why they would use each type of knowledge. Most students provided similar answers to the one shown in figure 6.5. that describes responses by Arisai. She states that both Nahua knowledge of plants and scientific studies can help people heal.



8. ¿En qué lugares y momentos usarías cada tipo de explicación? ¿por qué?

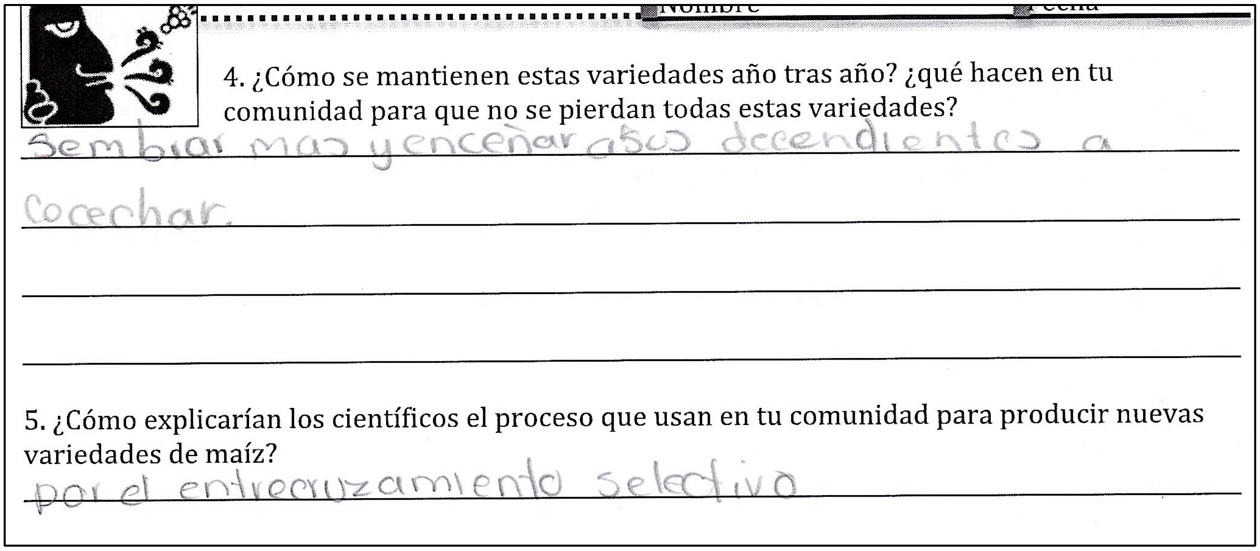
	Lugar o Momento en que la usarías	¿Por qué?
Explicación Azteca	Creencias como la herbolarea	algunas personas curan sus enfer con la herbolarea
Explicación de los Científicos Actuales	Imbestigan sobr el chocolate	porque la medicina cura tambien males pero con la ciencia

Figure 6.5. Arisai's worksheet after having discussed how would Aztecs and current scientist explain the bitterness of chocolate

In this example we can see how Arisai was able to reconcile both perspectives by stating that the two approaches (Nahua and WSK) can help people heal but through different means. She does not state that one approach is better than the other, but admits that the two worldviews may overlap and can sometimes reinforce one another (Snively & Corsiglia, 2001). Another example of successful border crossing of this type

Aztec explanation	Beliefs like healing with plants	Some people cure their illnesses using plants
Explanation from current scientists	Investigations about chocolate	Because medicine also cure illnesses but with science.

occurred when students learned about how their ancestors domesticated corn and about the Western science concept of selective cross-breeding (artificial selection). Students were able to analyze the phenomenon of corn cultivation and corn diversity using the two perspectives without experiences of conflict, as we can see in Yareli's worksehet (fig 6.6.).


Nombre Fecha

4. ¿Cómo se mantienen estas variedades año tras año? ¿qué hacen en tu comunidad para que no se pierdan todas estas variedades?

Sembrar mas y enceñar a sus decendientes a cocechar.

5. ¿Cómo explicarían los científicos el proceso que usan en tu comunidad para producir nuevas variedades de maíz?

por el entrecruzamiento selectivo

4. How do these varieties are maintained year after year? What does your community do so these varieties do not get lost?

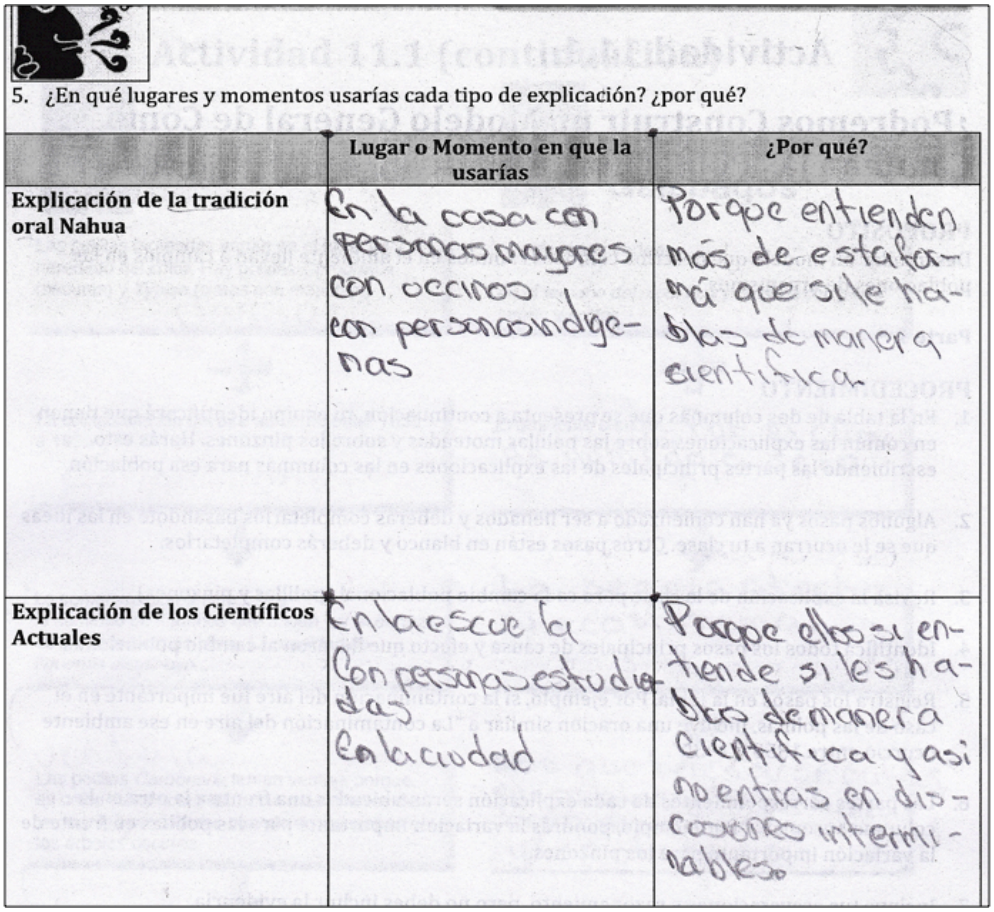
To plant more and teach their descendants to harvest

4. How would scientists explain the process that your community uses to produce new varieties of corn?

Because of selective breeding

Figure 6.6. Yareli's worksheet after learning about the origin and domestication of corn as part of the contribution of their culture to humanity

The examples presented thus far are representative of the majority of students for whom the border crossing experience was centered in analyzing a traditional narrative or a natural phenomenon from two points of view (Nahua and WSK). They are also examples of students sharing those types of knowledge in multiple contexts (school, home, community, and city). However, there is one more experience of border crossing that was not common but is worth discussing. Carmen and Ruben took on a practical approach to border crossing placing themselves in a position of agency, using each type of knowledge for their own convenience (Fig. 6.7) –as opposed to for the benefit of their community-.



5. ¿En qué lugares y momentos usarías cada tipo de explicación? ¿por qué?

	Lugar o Momento en que la usarías	¿Por qué?
Explicación de la tradición oral Nahua	En la casa con personas mayores con vecinos con personas indígenas	Porque entienden más de esta forma que si le hablas de manera científica.
Explicación de los Científicos Actuales	En la escuela con personas estudiadas en la ciudad	Porque ellos si entiende si les hablas de manera científica y así no entras en discusiones interminables

	Place or moment where you would use it	Why?
Explanation from the Nahua oral tradition	At home with elders, with neighbors, with indigenous people	Because they understand more in this way than if you talk to them in a scientific manner.
Explanation from current scientists	At school, with city people	Because they do understand if you talk to them in a scientific manner and that way you do not get into endless discussions.

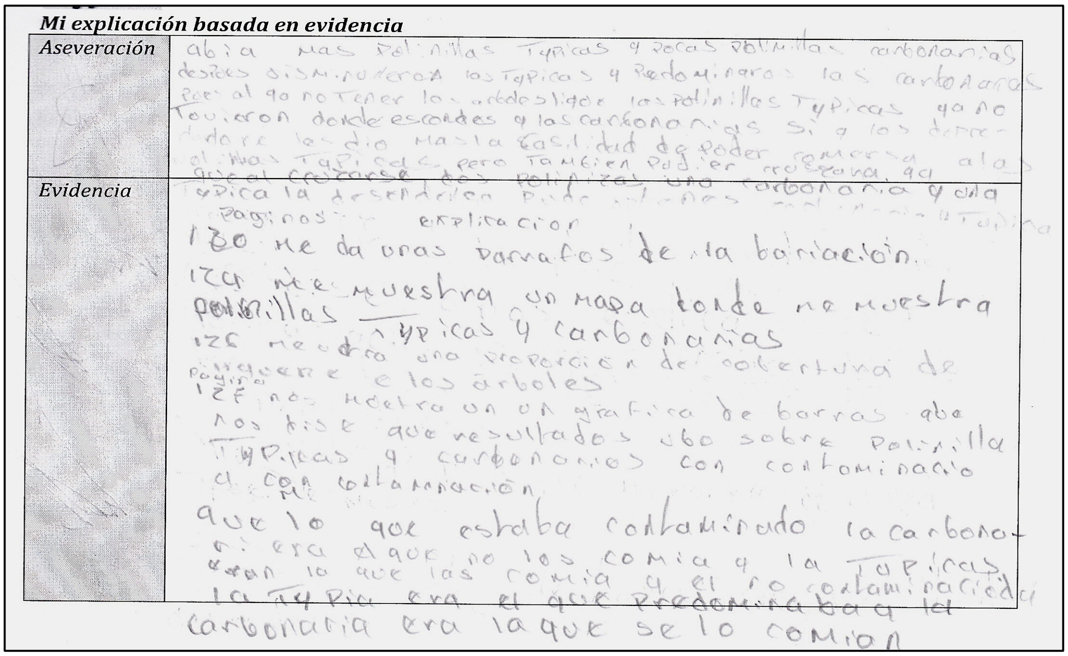
Figure 6.7. Carmen's worksheet after analyzing how would the Nahua tradition and Western science explain a different-looking dog.

In this example (Fig. 6.7) Carmen is assuming an agentic position by deciding when and how to use the traditional narratives characteristic of her culture and when to use Western science to serve her own interests (e.g. "avoiding endless conversations"). Carmen is prioritizing how she can better communicate with different people (elders, city people, people at school) instead of engaging in comparing and sharing different types of knowledge as it was observed in the previous examples. Although it was not common for students to place themselves at the center of these comparisons, Carmen and Ruben's experiences are indicative of how empowering it can be for some students to discover that by understanding multiple ways of seeing the world, they can be successful in multiple contexts. Being able to negotiate multiple perspectives while developing a sense of ownership and agency as producers and users of Western science and their own traditional knowledge is hallmark of equitable science classrooms (Barton & Tan, 2010; Carlone, Haun-Frank, & Webb, 2011; O'Neill, 2010). The fact that this was one of the students' experiences during the enactment of the unit is indicative of the positive results of providing opportunities for students to compare worldviews with a critical lens in the context of the science classroom (principles 4, 5, 6, and 7).

Moreover, it is noteworthy that becoming proficient in making these comparisons and studying traditional narratives, such as the nahuales story where one species turns into another, did not affect the ability of students to understand the Western science concept of population change and selective pressures. For xample, when students studied the case of the British Carbonaria moths they did not claim that the white moths were turning into black moths or vice versa, but they used the Western science concepts they had learned (Figure 6.8).

The fact that students were able to share the different versions of a traditional story they had heard at home, during class and were still able to analyze that same story from a Western science point of view, is evidence of successful border crossing. Even weeks after the lesson, they were able to use Western science to construct an explanation about a phenomenon that could easily lead to a transformational explanation.

The above-presented examples can all be considered successful instances of border crossing facilitated by the activities, scaffolds and instruction that were designed mainly based on principles 5 and 8 (incorporating traditional Nahua oral narratives to legitimize students' traditional knowledge, and including videos as a proxy for storytelling).



My evidence based explanation

Claim	There were more Typica moths than Carbonaria moths, later the Typicas went down and the Carbonarias were the most common because the trees did not have lichens and the Typicas could not hide anymore but the Carbonarias did. This gave predators the ease to eat the Typica moths.
Evidence	Page 120 gives me some paragraphs about variation and page 124 shows me a map where it shows me Typica and Carbonaria moths. Page 126 shows the proportion of lichen coverage in the trees. 127 shows us a bar graph that tells us the results about Typica and Carbonaria moths with pollution and with no pollution. When it was polluted the Carbonaria was the one not eaten and the Typica was the one eaten. And in the not polluted forest the Typica was abundant and the Carbonaria was the one eaten.

Figure 6.8. Sergio's worksheet to answer the question: Why has the population of moths changes over time?

These results suggest that incorporating narratives from students' culture and supporting students in taking multiple perspectives to analyze natural phenomena in the science class does facilitate border crossing. The results also suggest that a border crossing approach has a positive effect on students' learning of Western science concepts, since they were successful at explaining processes such as inheritance, natural selection and artificial selection during classes and in their worksheets (see Figs. 6.3 and 6.8); overall students exhibited significant learning gains (see chapter 5).

6.3.2. Discovering new possibilities: Nahua knowledge in science class and Western science knowledge in everyday life.

The second most common category in the analysis of the data corpus was "Using Western science knowledge for social justice". This result is in agreement with my field notes where I documented how students freely talked about how they have experienced discrimination during the activities designed based in principle 7 (Challenging the Status Quo and Developing Critical Consciousness). These activities were cognitively challenging, requiring students to comprehend complex readings, make sense of multiples sources of data, and critique explanations including biased claims, evidence or reasoning (see table 6.2). Students persevered in completing these activities even when they required multiple rounds of feedback from the teacher. Students actively participated in small group and whole class discussions associated with these activities, which indicates that students were cognitively engaged while learning with these activities (Blumenfeld, Kempler, & Krajcik, 2006).

Table 6.2. Field notes describing the discussion after reading 3.1 showing students' cognitive engagement.

October 3, Class: 1A. 8:00 AM

- The teacher asked all students to read reflection 3.1 in their teams, while they work on making sense of the reading she walks around and stops by every group observing what they are doing. Students are on task.

- (I am listening to the interactions of the group that is closer to where I am sitting) Fabiola is discussing and sharing her understanding of the reading with the team, insisting that malnourishment needs to be part of the evidence so the explanation provided in the worksheet is wrong. Alfonso replies saying that what is important in the reading is that the Havasupai were discriminated by the health insurance companies but he is not sure where to use that information because he does not understand what evidence is. Other members of the group seem equally confused.

- The teacher addresses the whole class and asks each group to share their ideas first (before going into critiquing the explanation presented in the student guide.)

- Nieves raises her hand immediately and says that diabetes type 2 is an inherited disease.

- Ruben A replies saying that malnourishment is making the Havasupai sick and not only their genes. He adds, "Not everything that is true is evidence". The other members of his team nod.

- Students in other groups seem confused by this statement and Alfonso asks (now so all the class can hear), "Teacher, what is evidence?"

- The teacher goes to the board and writes the claim in the students' worksheet. Then, she says that evidence is what supports the claim, a proof. She asks: "is the picture in the reading evidence?"

- Students do not agree.

- Teacher says, "Look at your facts sheet. What information there supports your claim? Ruben was right that not everything that is true is evidence but only those pieces of information supporting the claim. Continue discussing in teams and use your facts sheet now."

- In one group Fabiola and Lisbeth disagree with Alfonso that the right evidence to

support the claim (diabetes 2 is inherited among the Havasupai) was the high level of consanguinity among the Havasupai. Fabiola and Lisbeth insist that consanguinity is not included in all the risk factors for diabetes type 2 included in the facts sheet. Alfonso raises his hand calling the teacher. The teacher approaches the group and Alfonso asks, (while the other three members of the group watch attentively) "teacher, I do not understand. Diabetes type two is an inherited trait, why isn't that included in the risk factors of the facts sheet? I mean, the companies should not deny insurance but they are kind of right, no? (Fabiola and Ruben C shake their heads). The teacher says, "Remember when we talked about athletic performance? We discussed whether it was an inherited or acquired trait, what did we conclude?" Alfonso says, "It is both because you can inherit some stuff but you have to train too". Teacher says, "How is that similar to diabetes? Can you see the similarity? Think about it and try to reach agreement". She leaves for a different group. Ruben C tells the team that the risk factors are part of the environment and Alfonso nods. He starts reading what Lisbeth wrote in her worksheet and starts working on his own.

- The teacher continues having small conversations with different groups. After 17 minutes she goes to the front of the classroom and ask the class to make silence. Then she asks, "ok, we have discussed what is evidence. So do the insurance companies have evidence to deny insurance to the Havasupai only based in the fact that diabetes is inherited?

- Carmen says that the facts sheet mentioned poverty and malnourishment as risk factors for diabetes and those were not included in the companies' explanation so they were wrong.

- Fabiola eagerly raises her hand. She says that the Havasupai were discriminated, as she was discriminated when she went to the city with her mom and people looked down at her mom when she was speaking in Nahuatl.

(about 10 students are raising their hands waiting for their turn to participate)

- Sergio says that the Havasupai are being discriminated because they are fat and sick.

- Ruben A says that what is just is to provide help to all families with inherited

diseases.
- Nieves says, "when using genetic testing we need to respect everyone regardless of their clothing" [the use of traditional garments by Nahua people is heavily discriminated against in that region]
- Carmen says that the insurance companies were wrong because people get diabetes because of the genes and the environment so they have to give insurance to the Havasupai.
(Bell rings)
- The teacher says, "Ok, it seems we understood. As homework you will have to use your scientific knowledge to write recommendations for the secretary of health of Arizona, where the Havasupai live. We will discuss this on Friday".
(Class dismissed).

From this excerpt of the field notes it can be seen how students like Alfonso (lines 18-19 and 28-44) persevered to complete the task of critiquing the explanation that insurance companies used to deny insurance to the Havasupai even when he repeatedly struggled to understand what evidence was and what constituted evidence. On the other hand, this field notes entry allows us to see how students' like Fabiola were determined to use the science concepts she had learned to back up her ideas, even when her peers disagreed (lines 28-37 and 53-54). The interaction between Alfonso and Fabiola was quite interesting because Alfonso is a very popular boy among the 7th graders and Fabiola tends to be a very shy girl during science classes and also during recess, when she hangs out mainly with two other girls. Fabiola was especially participative during this class and she was adamant at defending her point of view and communicating her understanding to her team and to the class. It seems, by what she shared with the class about personally experiencing discrimination (lines 53-54), that she had a personal motivation to become engaged in this activity and to find new tools to question her experience with this discrimination. The way Fabiola positioned herself during this interaction is one more example of how, by learning with this contextualized unit, students construct an identity around agency and empowerement that allows them to become experts by selectively using their knowledge of multiple worldviews to assert their own positions in the science classroom (Barton & Tan, 2010). The fact that a shy girl like Fabiola was supported to gain agency and empowerment by learning with this contextualized unit has important implications for her future educational attainment; those traits become key when she is negotiating her pursuing of higher education with her family[7]. Therefore, the development of students' agency becomes an essential goal of science curricula that is committed with providing access to science to all those students who are marginalized in the societies where they live.

During the enactment of this contextualized unit students had multiple opportunities to practice agency and to adopt a critical stance towards the social injustices they experience. These opportunities triggered cognitive engagement, and therefore eased students' learning of science. The activities in which the students could use the Western science concepts they had learned to be critical of social inequalities they had faced, were the activities during which students students showed sustained cognitive engagement.

These results are further supported by the students' final interviews and students' work (worksheets). During the final interview when students were asked to name their favorite moment or activity of the science classes (we started the school year with this unit), most of them mentioned having the opportunity to discuss discrimination. Through those discussions about discrimination, students realized there is no foundation to the idea that some people are more intelligent or better than others

[7] In Nahua communities it is still common for young girls to have to engage in complicated negotiations with their families to pursue higher education, because it means leaving their communities and departing from traditional gender expectations.

just based on their phenotype or ethnicity. Juanito, for example, provided an interesting answer in his interview:

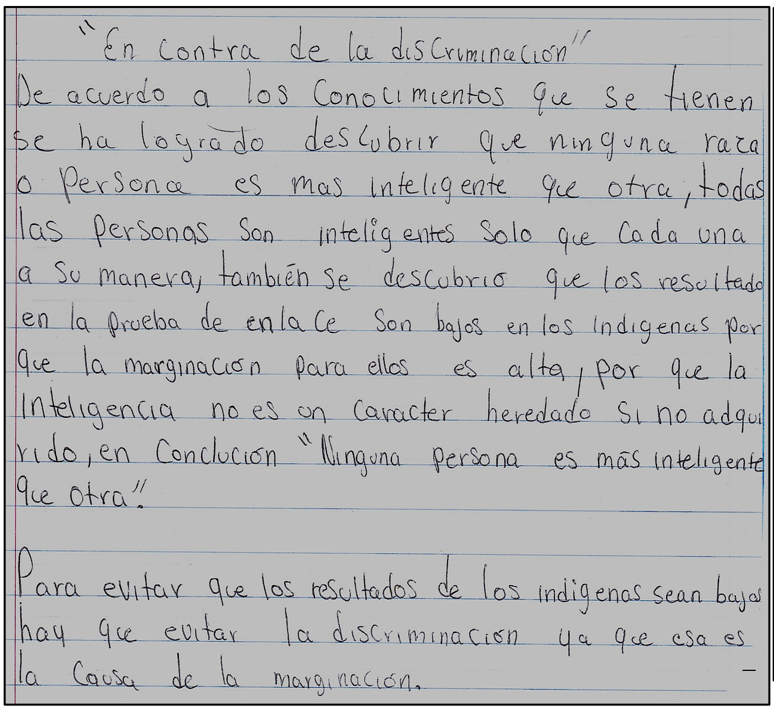
I: From all what we have done in science class what is what you have liked the most?
Juanito: the activity about not discriminating people.
I: Why did you like that one?
J: Because not discriminating people is important for the maintenance of the culture. [Nahua traditions]

In his answer Juanito links discrimination with the survival of his own culture. In this context it is only logical that a student takes great interest in learning new ideas and tools that will help him combat a social reality that is detrimental to his own way of living. Similarly, Nieves provided the following answer:

I: From all what we have done in science class what is what you have liked the most?
Nieves: not discriminating people
I: Why did you like that one?
N: Because I learned that it is not because of being indigenous that we can't progress.

In this case Nieves also makes a personal connection with the idea of discrimination. It seems from her response that learning that there is no scientific base to discriminate against indigenous people gave her confidence to believe she can accomplish her goals. When students see Western science as a playing a role in the achievement of their own goals (e.g. fighting discrimination) they would see science as something of personal relevance and value this type of knowledge, thus becoming motivated to learn it (Bang & Medin, 2010).

Feeling empowered to use Western science concepts for questioning discrimination was a common thread among students. This tendency was evident in students' worksheets too. For example, students were asked to write a short article they would like to see published in a local newspaper about what they had learned in the science class. Once again, many students mentioned discrimination. Laura, for example uses her science knowledge to conclude that intelligence is not an inherited trait but an acquired trait (Fig. 6.9), understanding discrimination as an environmental factor that affects individual traits.


"En contra de la discriminación"
De acuerdo a los conocimientos que se tienen se ha logrado descubrir que ninguna raza o persona es mas inteligente que otra, todas las personas son inteligentes solo que cada una a su manera, también se descubrio que los resultados en la prueba de enlace son bajos en los indigenas por que la marginación para ellos es alta, por que la inteligencia no es un caracter heredado si no adquirido, en conclución "Ninguna persona es más inteligente que otra".

Para evitar que los resultados de los indigenas sean bajos hay que evitar la discriminación ya que esa es la causa de la marginación.

"Against Discrimination"
According to the knowledge science has, it has been discovered that not any human race is more intelligent than the other. All people are intelligent, but each one in their own way. It was also discovered that the results of the ENLACE assessment are low for indigenous students because marginalization for them is high, because intelligence is not an inherited trait but it is an acquired trait. In conclusion, "not a single person is more intelligent than the other".
To avoid low scores in indigenous students we have to prevent discrimination because that is the cause of marginalization.

Figure 6.9. Laura's short text about how would she use her science knowledge to combat discrimination.

The fact that Laura and other students started thinking about marginalization and discrimination as environmental factors affecting individual traits is noteworthy, because it shows how middle school students are capable of an expanded understanding of "environmental factors". It is very important that students start engaging in this type of reasoning, because all current research in public health and epidemiology shows that social environment affects health over the life course (Williams, Mohammed, Leavell, & Collins, 2010). Moreover, these studies shows that discrimination and racism have detrimental effects on a broad range of health status indicators such as poor sexual functioning, abdominal fat, coronary artery calcification, the incidence of uterine fibroids, and breast cancer (Williams et al., 2012). Therefore, it is highly relevant to discuss discrimination in the science classroom not only for students to learn about up-to-date genetics or public health issues and to empower students to pursue science but, in addition, as an ethical imperative to educate a citizenry fully aware of how to take care of their health and with the tools to advocate for themselves.

In this context, principle 7 (Challenging the Status Quo and Developing Critical Consciousness) proves to be highly relevant and personal for students as well as aligned with current scientific knowledge on human health. Supporting students in using their knowledge of genetics and inheritance to be critical about the social inequalities they face was a successful strategy that also had effect of making students feel confident to use their traditional knowledge in class and deriving pride in doing it.

To better understand whether the principles 4, 5, 6, and 8 had the intended effect of facilitating the use of traditional knowledge by students in science classes, during the final interview, students were asked the question, “Did you have the opportunity to use the knowledge of your community in the science class?” during the final interview. Students maintained that they were able to use the knowledge they had learned at home from elders and parents as the following answers demonstrate:

Daniel I: Yes. I used my knowledge for the readings and in the questions.

Interviewer: Can you give an example?

Daniel I: In the reading about nahuales, and hmm… when we talked about healing.

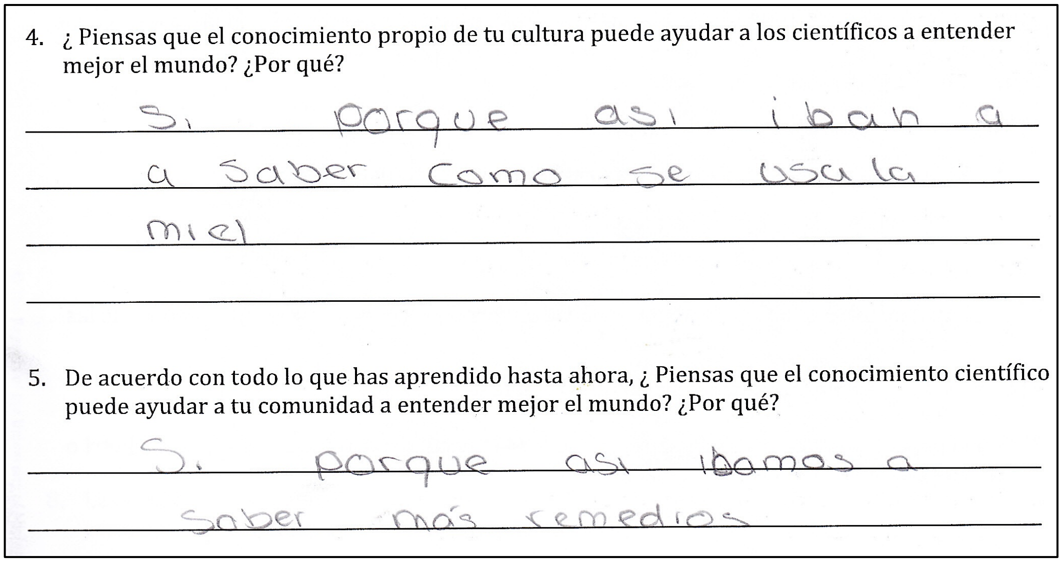
Interviewer: Ok. How do you feel when we use the knowledge of your community in the science class?

Daniel I: Happy, because it comes from my community.

Imanol: Yes, like just recently we talked about nahuales. That is an indigenous story that has been told generation after generation.
Interviewer: Ok. How do you feel when we use the knowledge of your community in the science class?
Imanol: well… proud of maintaining the tradition of storytelling.

Juana: Yes, when we talked about the different kinds of pigs, or about the origin of corn.
Interviewer: Ok. How do you feel when we use the knowledge of your community in the science class?
Juana: I feel happy to share what I know.

As it can be observed from Daniel, Imanol, and Juana's interviews, students identified multiple opportunities during the enactment of the contextualized unit to use and share their traditional knowledge [Principles 4, 5, 6, 8]. Also, they all mentioned that they experienced positive affect when using and sharing the knowledge of their community. Part of this positive affect was feeling pride in their ethnic identity (being Nahua or being indigenous) while learning Western science concepts and comparing how their traditional knowledge overlapped, complemented or was different from Western science. This pride in their culture facilitated a successful border crossing experience for students because they could see the value in the two types of knowledge and they did not see them as antagonistic (Fig 6.10) (G. S. Aikenhead, 1997; G. Aikenhead, 2002; Snively & Corsiglia, 2001).


4. ¿ Piensas que el conocimiento propio de tu cultura puede ayudar a los científicos a entender mejor el mundo? ¿Por qué?

Si porque asi iban a a saber como se usa la miel

5. De acuerdo con todo lo que has aprendido hasta ahora, ¿ Piensas que el conocimiento científico puede ayudar a tu comunidad a entender mejor el mundo? ¿Por qué?

Si porque asi ibamos a saber más remedios

4. Do you think that your culture's knowledge can help scientists better understand the world? Why?
Yes, because that way they would know how to use honey.

5. According to what you have learned so far, do you think that the scientific knowledge can help your community to better understand the world? Why?
Yes, because this way we would know more medicines

Figure 6.10. Ruben's worksheet after discussing how Aztecs and Nahuas have traditionally used honey for healing with success

As it can be seen in figure 6.10, the questions in the students' worksheets supported students in reflecting about the possibility that their knowledge was valuable to Western scientists and that Western science was valuable to their community [Principle 4]. In this specific example (fig. 6.10) the student identifies one of the multiple cases that were presented in the unit in which traditional Nahua knowledge helped advance Western science and identifies an area that is highly relevant to the Nahua culture (traditional medicine) that can be advanced using Western science. This specific worksheet was presented at the end of the unit and students completed it individually. The example in figure 6.10 is representative of most students' responses, which provides additional support to conclude that the contextualized unit had a positive effect in the students' ability to cross borders between their traditional knowledge and Western science. However, not all students were smooth border crossers, as I will detail in the following section (6.3.3).

The results discussed thus far further support the scholarship of science education for indigenous students (Aikenhead, 2001, 2002; Snively & Corsiglia, 2001, 2005). The results support the idea that students' traditional knowledge does belong in the science classroom when approached from a border crossing perspective in which students have opportunities to understand how their traditional knowledge overlaps, complements, or even contradicts Western science. Therefore, creating opportunities for students to use their traditional knowledge becomes a powerful learning trigger that increases students' willingness to invest cognitive resources in studying narratives they are familiar with from alternative perspectives (WSK) without experiencing negative effect. A border crossing approach to curriculum design and instruction has the potential to support minority students to master complex science concepts while at the same time developing pride in their ethnic identities, thus operationalizing the principles of Culturally Relevant Pedagogy (Ladson-Billings, 1995; Ladson-Billings, 1995) and Cross-Cultural science education (Aikenhead, 2006; G. Aikenhead, 2001, 2002).

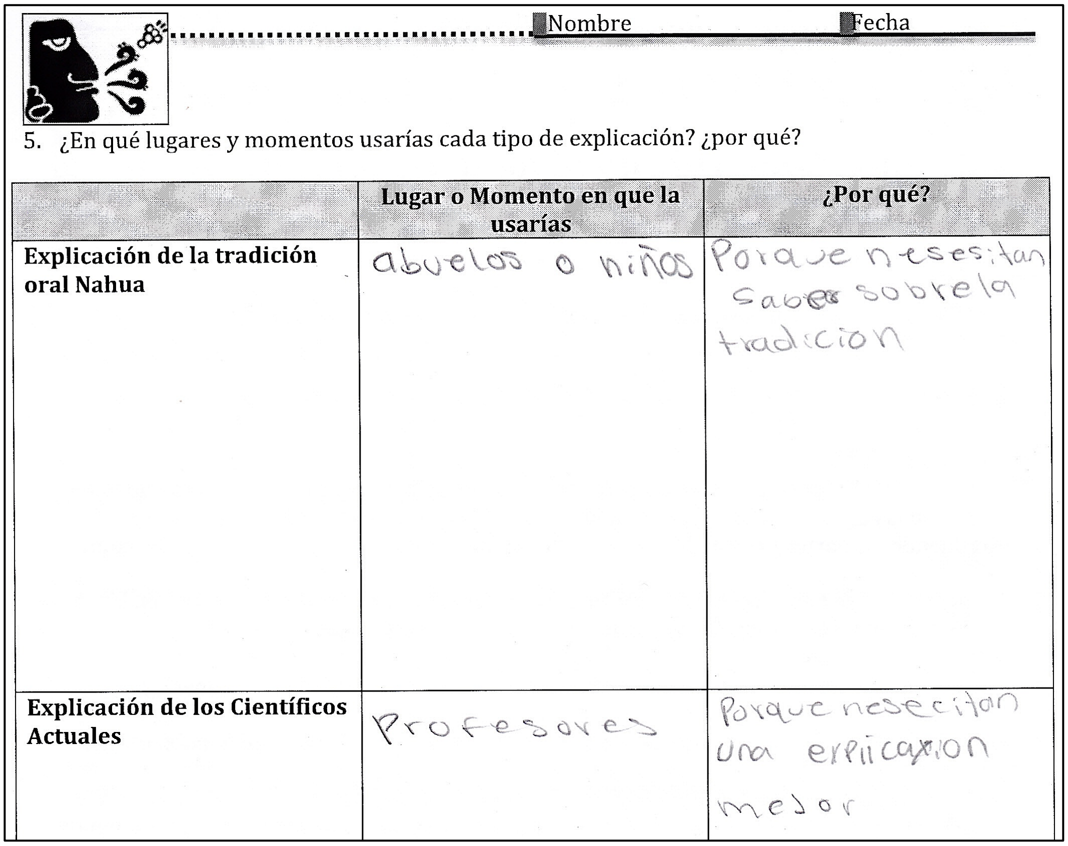
6.3.3. Difficulties in the border crossing experience

Thus far I have described successful stories of border crossing. However, engaging in border crossing was a challenging activity for students and some of them struggled during the enactment of the unit. As observed in Table 6.1, the difficulties in border crossing have a lower frequency of reference but they still represent an important pattern that can signal ways to refine and improve the contextualization principles suggested in this dissertation. Also, all the sources coded "internalized oppression" belonged to students whom at some point of the unit enactment experienced difficulties border crossing between cultures which explains the clustering observed in figure 6.11. When making sense of all the worksheets and interviews in which students demonstrated difficulties transitioning from their culture to Western science or struggled to analyze a phenomenon from multiple perspectives, I classified this pool of sources into four categories: internalized oppression (believing that WSK is better than their traditional knowledge), language, school- home separation, and epistemology.

The first of these categories, internalized oppression, captures the idea that students have been exposed through school discourses and mass media, to the idea that their traditional knowledge is inferior to Western science, meaning, only explanations and reasoning based on Western science has validity (Gómez Lara, 2008). I have multiple entries in my field notes journal of instances in which a science teacher would tell the students that their traditional beliefs are superstition and they go to school to learn what is true. This is a common discourse experienced by Nahua people in Mexico as evidenced in multiple interviews with elders (see Chapter 4). Students are constantly exposed to these ideas and unfortunately some of them begin internalizing this oppressive discourse early in their lives. Precisely because one of the findings in the pre-contextualization stage was delegitimization of Nahua knowledge by mainstream society, I designed principle 5, 6, and 7. Principle 5 introduced traditional Nahua narratives in the curriculum and portrayed them as a legitimate way of knowing; principle 6, to introduce elements of the Nahua language in the unit; and principle 7, challenged oppressive narratives that negatively impact students' self esteem and a healthy development of their ethnic identity. This combination of principles proved to be effective to facilitate border crossing for most students, as described in the prior sections, but it was not enough for all students to be successful border crossers.

Believing in the validity of their own knowledge was difficult for high achievers, but students who were reported to be average or academically struggling did not show this pattern. One possible explanation is that high achievers have been well served by this oppressive narrative throughout their schooling process, being praised for reciting Western science knowledge, demonstrating competence in Western ways, and avoiding mention of their traditional knowledge or speaking their native language. The four students who maintained until the end of the unit that Western science was "better" than their community knowledge were high achievers[8]. For example, after analyzing the story of Nahuales, that for most students involved feeling pride and enjoyment of sharing their traditional knowledge, Ronaldo wrote in his worksheet that he would only use that traditional narrative with children or elders but not with teachers because they need "a better explanation" he can only provide using Western science knowledge (Fig 6.11 and 6.12).

[8] Unfortunately, I did not collect information about the students' family details, such as parental occupation. Most adults in this community combine agricultural activities with carpentry. Other less common occupations are elementary teacher, and government employee. Because of this lack of information it is not possible to infer the effect of parental occupation (their degree of involvement in the mainstream Mexican society) in the students' difficulties at border crossing. All the claims presented in this chapter are based solely on the students' experiences in the classroom and out of the classroom experiences reported by them.



[redacted]Nombre [redacted]Fecha

5. ¿En qué lugares y momentos usarías cada tipo de explicación? ¿por qué?

	Lugar o Momento en que la usarías	¿Por qué?
Explicación de la tradición oral Nahua	abuelos o niños	Porque nesesitan saber sobre la tradicion
Explicación de los Científicos Actuales	Profesores	Porque nesecitan una explicaxion mejor

	Place or moment where you would use it	Why?
Explanation from the Nahua oral tradition	Grandparents and children	Because they need to know about the traditions
Explanation from current scientists	Teachers	Because they need a better explanation.

Figure 6.11. Ronaldo's worksheet after analyzing how would the Nahua tradition and Western science explain a different-looking dog.

8. ¿En qué lugares y momentos usarías cada tipo de explicación? ¿por qué?

	Lugar o Momento en que la usarías	¿Por qué?
Explicación Azteca	las personas de comonidad	Entender mejor los conocimientos de los antiguos
Explicación de los Científicos Actuales	Ciudad escuela	Para tener mejores conocimientos sobre el tema

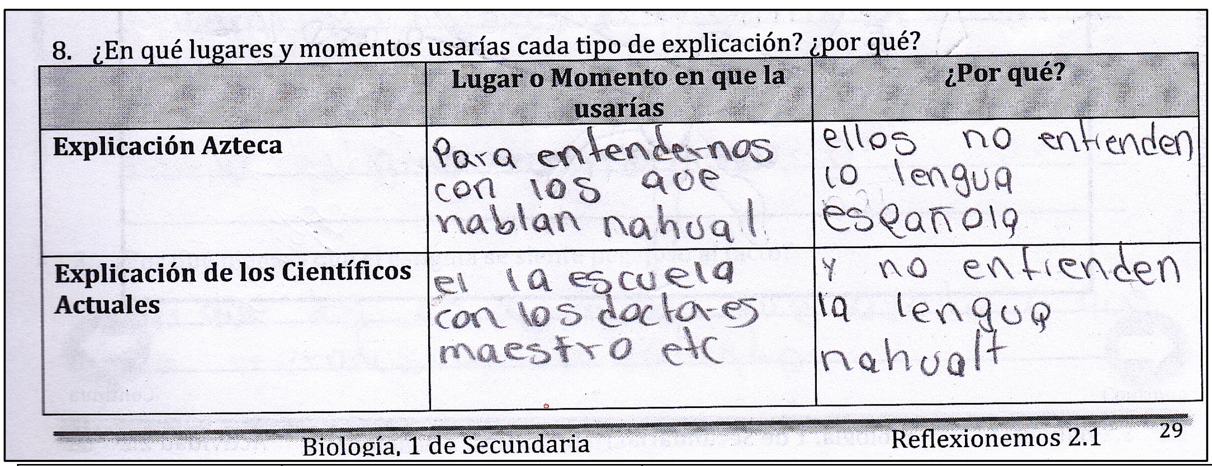
	Place or moment where you would use it	Why?
Aztec explanation	People of the community	Better understand the knowledge of the ancestors
Explanation from current scientists	City School	Better understand the knowledge of this topic.

Figure 6.12. Christopher's worksheet after having discussed how would Aztecs and current scientist explain the bitterness of chocolate

Believing that the knowledge of their communities is somehow "inferior" is an oppressive idea that students like Ronaldo have internalized throughout the six years of elementary school by being rewarded for not using their language and traditional knowledge at school (Gómez Lara, 2008). This internalized oppression not only makes it difficult for students to cross borders between science and their traditional knowledge, but it also leads to problematic relationships between adolescents and their families, which can go in detriment of students' academic achievement and future adjustment to post-secondary education (Bernal, 2002; Castagno & Brayboy, 2008).

Part of this oppressive narrative of delegitimization of the Nahua knowledge includes a devaluation of the Nahuatl language. Although most students who participated in this study attended bilingual elementary schools, they learn very early on that Nahuatl is not spoken in the city, on media, or in school after elementary. Students start having a science teacher (elementary schools have a single teacher for all subjects) when they start middle school and at that point, all instruction occurs in Spanish, so they receive the implicit message that science and academic subjects are done in Spanish and that Nahuatl only belongs to the family/community realm. In other words, Nahuatl is not a language to produce knowledge that would be valued by their teachers or would help them to succeed academically. This idea makes it difficult for students to believe that they can use science in their lives and, that their ethnic identity is incompatible with doing/learning science, thus impeding border crossing between students' culture and Western science. This belief that Western science is incompatible with speaking Nahuatl is exemplified in Nieves' worksheet that she completed after discussing how Aztecs talked about the bitter flavor of chocolate and how scientists do (Fig. 6.13).

	Place or moment where you would use it	Why?



8. ¿En qué lugares y momentos usarías cada tipo de explicación? ¿por qué?

	Lugar o Momento en que la usarías	¿Por qué?
Explicación Azteca	Para entendernos con los que hablan nahual.	ellos no entienden la lengua español
Explicación de los Científicos Actuales	el la escuela con los doctores maestro etc	y no entienden la lengua nahualt

Biología, 1 de Secundaria — Reflexionemos 2.1 — 29

Aztec explanation	To communicate with those who speak Nahuatl	They do not understand the Spanish language
Explanation from current scientists	At school with doctors, teachers, etc.	And do not understand the Nahuatl language.

Figure 6.13. Nieves' worksheet after having discussed how would Aztecs and current scientist explain the bitterness of chocolate

In this worksheet Nieves communicates her idea that she would only use Western science at school, with teachers and medical doctors because they do not understand the

Nahuatl knowledge and that she would not use it in her community because they do not understand Spanish, suggesting that she indeed believes Western science can only be communicated in Spanish. This belief may not impede that students obtain high grades, but it has the potential to make it difficult for students to see the value in learning and using Western science in their lives, thus decreasing their motivation to engage in the science class as Nieves demonstrated in her midpoint interview:

Interviewer: What classes do you like the least?

Nieves: the science class

I: why don't you like it?

Nieves: because I get bored, it's too much time.

I: do you think you understand the ideas you learn in that class?

Nieves: yes, but I don't like it.

I: ok, I see. Do you share what you learn in your science class with your family or friends?

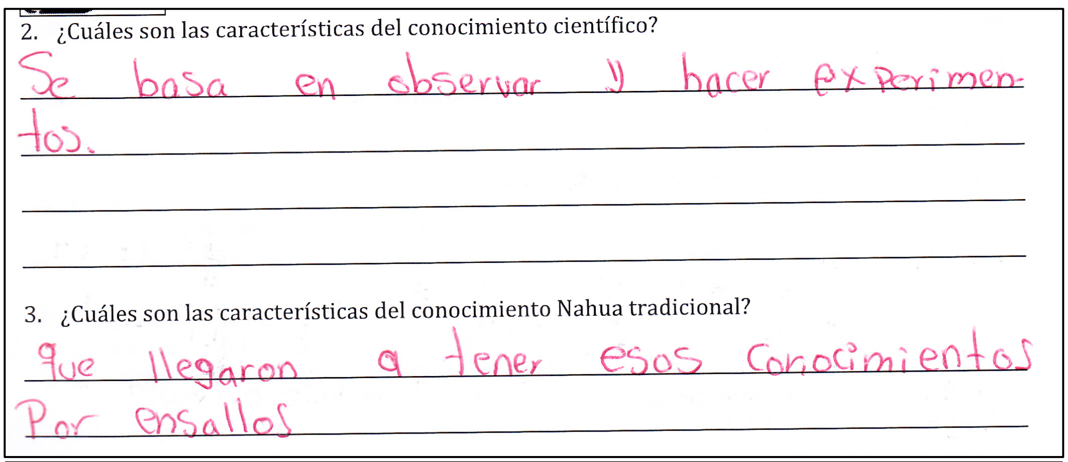
Nieves: only with my sister, but she thought it was boring too.

These statements by Nieves were surprising because she was always engaged in class, she completed all assignments, she showed no difficulties completing complex tasks such as pedigrees and she even frequently helped her friends to complete various tasks in the science class. Also, she is described as a high achiever by other teachers. These results suggest that students like Nieves have learned the behaviors that are rewarded at school but it does not mean they develop true interest in learning science, and is therefore unlikely that they would pursue science in the future. Nieves' idea that what they learn at school would not be understood in her community makes it difficult for her, and other students who think like her, to cross borders between their culture and Western science and ultimately reduces their access to science.

Moreover, these results suggest that for successful border crossing to occur between students' culture and Western science, when students are bilingual, the two languages should be present in the science classroom, an idea that is aligned with critical and culturally relevant pedagogies (Bernal, 2002; Cajete, 1994; Castagno & Brayboy, 2008). Even if the science teacher is not bilingual, asking community members to get involved in translating some worksheets that students can complete with their families can introduce the idea that science has a place in their day-to-day lives, thus increasing their motivation. Even when only three of the four students experiencing marked difficulties in border crossing mentioned language, this is a very important variable to take into account since language plays an essential role in how we understand the world, interact with others, and build knowledge (Lemke, 2001; Rogoff, 2012). Denying indigenous students the opportunity to use their bilingualism to achieve academically in science brings the risk of disengagement and marginalization of indigenous students from school science.

Although the home language component is the base of principle 6, the use of the Nahuatl language in the enactment of the unit was underdeveloped and that is indeed a limitation of this study. I do not speak Nahuatl and it would have been extremely difficult for me to support and analyze the enactment of the unit having had a big instructional component in Nahuatl language. Also, none of the teachers in the school were Nahuatl speakers. The teacher who participated in this study is part of the community and understands spoken Nahuatl but she is not a fluent speaker of the language. This limitation however, points to the need to emphasize contextualization principle 6 in future iterations of the unit or in contextualizing other science materials for allowing access to science to multilingual/multicultural students.

Another limitation of the contextualized unit that may have led to some students experiencing difficulties in border crossing was the lacking of an epistemological component in the unit. A better understanding of the characteristics of Western science as a way of knowing could have facilitated that all students could successfully engage in comparing multiple ways of knowing and ultimately ease their border crossing between their culture and Western science. The only instance in the unit where there was a scaffolded discussion and a worksheet for students to learn and think about the characteristics of Western science knowledge was as part of principle 6 after students completed the activity of honey for healing (see Chapter 5). Although students succeeded in this activity (fig. 6.14), this was hardly enough to support students in understanding the nature of Western science and use this knowledge to better understand how Western science is similar or different from their own traditional knowledge.



2. ¿Cuáles son las características del conocimiento científico?
Se basa en observar y hacer experimentos.

3. ¿Cuáles son las características del conocimiento Nahua tradicional?
que llegaron a tener esos conocimientos por ensallos

2. What are the characteristics of the scientific knowledge?
It is based in observing and doing experiments

3. What are the characteristics of the Nahua traditional knowledge?
That they came to have that knowledge by trials

Figure 6.14. Ruben's worksheet after having discussed how would Aztecs and current scientist explain the bitterness of chocolate

Engaging in comparisons between multiple ways of knowledge is a cognitively challenging activity and it can be greatly facilitated by supporting students in understanding the nature of science. Learning about the nature of different types of knowledge should be a precursor for successful border crossing between different ways of knowing or different cultures. However, epistemology is a complex content to tackle and would require time and multiple exposures to be taught and learned (Khishfe, 2008), making it implausible to include those contents and practices in only a single IQWST unit, that is typically 8-weeks long. In the case of this study the enactment of the contextualized unit took 11 weeks and it would have been impossible to fit an epistemological component within this time framework. A possible solution to support students to gain a working understanding of the nature of science that takes into consideration time constraints and the complexity of the subject providing students with foundational knowledge of epistemology that can be applied and refined throughout multiple thematic units during the middle school years. This approach would prepare students to be smooth border crossers, having the tools to easily identify in which contexts is more effective to use a particular way of knowing, thus increasing their agency and chances of both access to science and healthy development of their ethnic identity.

6.3.4. Conclusions

In this chapter I presented the different types of border crossing between traditional knowledge and Western science knowledge, that students experienced when learning with the contextualized learning unit on inheritance and natural selection. In general, students were capable of navigating these two ways of knowing in the classroom but there were differences in how students perceived they could do this border crossing outside of the classroom. As noted before, an indication of the success of the contextualization process presented in this dissertation is that seventh grade students could successfully engage in a challenging activity such as reasoning about one phenomenon from the perspective of two worldviews, while reporting learning gains in Western science concepts, developing pride of their own culture, and showing enthusiasm for learning Western science at school and in their future. These results are evidence that the activities based on principles 4, 5, 6, 7, and 8 supported students in gaining proficiency at border crossing between cultures. Also, these results are aligned with research showing that a border crossing approach to teaching science facilitates that science classes can speak to students' identities, thus fostering students' cognitive engagement and construction of knowledge (Barton & Tan, 2010; Kinloch, 2012).

Principles 4[9], 5[10], 6[11], and 8[12] (see table 4.4) gave a place and a voice to indigenous knowledge in the science class and contributed to a sense of respect and validation for indigenous knowledge and traditions alongside Western science. According to Aikenhead (2001, p.8), these are core elements for indigenous students to feel that their identity has a legitimate place in the science classroom so that "Cultural negotiation could occur. Coming to knowing had a legitimate place. The discourse of power no longer resided with the teacher. Power was more evenly shared." The shift in the power relationships in the classroom added to the legitimization of students' knowledge and culture and greatly facilitated students' learning of complex Western science concepts during the enactment of the unit. This conclusion is further supported by the findings of Castagno and Brayboy's (2008) that those same factors have been shown to have positive effects on North American indigenous students' performance and attainment measures.

The positive effects in students' performance were not the only outcomes of principles 4, 5, 6, and 8. These principles also had positive effects in students' cognitive engagement and healthy development of an ethnic identity by reducing the cultural gap between students and school science and the pressure of assimilation into a foreign culture (Agbo, 2004; Aikenhead, 2006; Aikenhead, 2001, 2002). This reduction was achieved by connecting traditional Nahua narratives and traditional knowledge of

[9] Principle 4: Using traditional Nahua knowledge and practices as a context to explore Western science concepts and to engage adult members of the community in the classroom
[10] Principle 5: Incorporating traditional Nahua oral narratives to legitimize students' traditional knowledge in the context of the science classroom, thus facilitating border crossing into Western science.
[11] Principle 6: Revaluing Nahua narratives and language through curricular materials.
[12] Principle 8: Including videos as a proxy for storytelling (oral narratives).

plants, medicine, and agriculture to the Western concepts of inheritance and natural selection. Connecting traditional Nahua concepts to Western science concepts also fostered students' cultural competence. In summary, by facilitating academic achievement and cultural competence, principles 4, 5, 6, and 8 can be considered as successful examples of the enactment of Culturally Relevant Pedagogy (Ladson-Billings, 2006; Ladson-Billings, 1995).

The third principle of Culturally Relevant Pedagogy is sociopolitical consciousness. The idea of sociopolitical consciousness was operationalized in the IQWST unit through contextualization principle 7 (Challenging the Status Quo and Developing Critical Consciousness). The activities that were designed based on this principle, supported students to use their knowledge of Western science to be critical of their social position and context, in their case, experiencing racial discrimination and marginalization because of being indigenous. Principle seven not only illustrates a possible way to enact sociopolitical consciousness in the science classroom but it also reveals my ethical position that science education must prepare marginalized students to use their science knowledge in critical ways to transform their situation and become effective agents for social change.

In this sense, I echo Ladson-Billings (2006) in understanding the curriculum as a cultural artifact that is not ideologically neutral. Therefore, contextualization principle 7 addresses social injustice by supporting students in using their science knowledge critically to challenge racial discrimination. This element, combined with exposing students to successful individuals from their culture, and providing them with opportunities to navigate multiple ways of knowing favors that indigenous students learn the skills and knowledge of the dominant culture that oppresses them while gaining empowerment to speak against inequitable practices, thus contributing to social change (G. Aikenhead, 2002; Kinloch, 2012; Ladson-Billings, 2006; C. D. Pewewardy, 2003).

Castagno & Brayboy (2008) note that despite the important role racial discrimination has played and continues to play in the academic achievement of indigenous students, racism is rarely integrated with analyses of Culturally Relevant Pedagogy or integrated into the curricula of the different subject matters. Therefore, the present dissertation constitutes and example of how to integrate a social issue that marginalizes students into the science curriculum in a way that promotes students' agency, learning, and pride. Principle 7 in combination with principles 4, 5, 6, and 8, not only contributes to create concrete examples of science education that is meaningful to students, but also socially responsible and culturally relevant.

The combination of principles 4 to 8 combined with the principles discussed in chapter 6 supported students in experiencing border crossing between their culture and Western science. All of the worksheets that specifically supported border crossing were named "Let's Reflect" because the process in which students engaged was an assisted but autonomous reflection of how their culture's knowledge was similar or different to Western science, and how and when they would use each type of knowledge. This flexibility and reflectivity allowed the observation of multiple experiences of border crossing that I grouped in six descriptive categories presented in table 6.5.

Table 6.3. Types of border crossing between experienced by students.

1	WSK is "better" or provides better explanations than traditional knowledge. This idea is usually derived from internalized oppression (mainstream societal discourses that devalue Nahua knowledge).
2	Traditional knowledge is used only in the community but WSK is used in the city, at school, or for interacting with teachers. Students are not yet thinking of WSK as a type of knowledge they can use in their daily lives or of traditional knowledge as something they can use and share outside of their community.
3	Traditional knowledge can only be built and communicated in Nahuatl while WSK is built and communicated in Spanish only.
4	The student chooses in which contexts to use each type of knowledge for having more efficient communication or serving any other personal goal. This practical approach denotes agency in deciding when and how to use different discourses for one's own benefit.
5	The student sees WSK as useful to understand various aspects of her own culture and believes that traditional knowledge can help scientist better understand the world.
6	The student is able to explain the same phenomenon from the perspective of traditional knowledge as well as from the perspective of WSK without conflict or inaccuracies.

These categories of border crossing are different from Costa's (1995) and Aikenhead's (2001) types of border crossing in that their classification is based on comparing the culture of school, the culture of science, and the students' culture and assessing the potential difficulties of border crossing that students experience according to the compatibility (or incompatibility) between those cultures. In contrast, the classification that I am proposing here is based on how and when students themselves used each type of knowledge (Western science or Indigenous). Therefore, this classification describes the border crossing experience from the students' point of view and not from my own assessment of how congruent the students' epistemological commitments and understanding are with those of Western science (Aikenhead, 2001; Costa, 1995). Categories 1 to 3 describe some of the difficulties students can face when trying to engage in border crossing between cultures, while categories 4 to 6 describe smoother experiences of border crossing in which students exhibit agency, appreciation and respect for the two ways of knowing, and proficiency at using each way of knowing for explaining phenomena.

Developing this ease at border crossing is fundamental for indigenous students to learn the knowledge of nature of another culture and to choose which worldview better fulfills their goals at any given moment (Aikenhead, 2001). This skill is an advantage when living in a multicultural society, facilitating that students succeed in multiple contexts and become effective agents of social change. Taking into account these important benefits of becoming proficient at border crossing, it is important that culture minority students are not left to manage this crossing on their own but that teachers and students can count on contextualized science curricula that scaffolds and facilitates this process. One important risk of leaving students and teachers unsupported to learn and teach science from a border crossing approach is falling into relativistic stances and pseudoscience, instead of understanding the differences and similarities of different epistemological traditions. For example, the story of Adam and Eve as the origin of humanity is part of the Christian and Judaism traditions, and it is important for many peoples as part of their faith and heritage. It would not be appropriate for the science teacher to tell students that their traditions are "wrong", however, it is would be necessary to highlight that the story does not belong to Western science. Western science has different ways to explain the world. In the case of the origin of humans, the fossil record and genetics helped scientist to formulate an evidence-based explanation that does not include a creator, Adam, or Eve. Attempts to "bridge" between the two traditions without a good understanding of them can lead to what we see in the Museum of Creation in Kentucky, U.S.A, where elements of the two traditions are combined in ways that misrepresent them both. Exhibits such as the Garden of Eden, showing Adam, Eve, and dinosaurs, are scientifically inaccurate and dinosaurs are certainly not important for the Christian faith. The approach of border crossing presented in this dissertation does not endorse such approaches, but highlights the importance of supporting students to become competent in their own tradition while becoming scientifically literate in the Western tradition. Supporting students and teachers through quality curricula to learn and teach science as border crossing avoids relativistic and pseudoscience positions that are a disservice to students.

In this sense, the contextualized IQWST unit presented in this dissertation was successful at scaffolding border crossing by attending to students' context (incorporating Native language and culture from elders and others in the community) while preparing them for succeeding in a globalized world where educational attainment and participatory citizenship can be more easily accessed when individuals become scientifically literate. In general terms, the contextualized unit embodied what North American indigenous researchers define as culturally relevant curricula for indigenous students:

> "(a) capitalizes on students' cultural backgrounds rather than attempting to override or negate them; (b) is good for all students; (c) is integrated and interdisciplinary; (d) is authentic and child centered, connected to children's real lives; (e) develops critical thinking skills; (f) incorporates cooperative learning and whole language strategies; (g) is supported by staff development and preservice preparation; and (h) is part of a coordinated, building-wide strategy" (Klug & Whitfield, 2003, p. 151).

Among those principles there are three that were not fully developed in the unit or not incorporated at all, and constitute a limitation of this study. Students' native language was incorporated timidly in the unit, as described in the prior section, limiting the range of experiences that students could have had when border crossing. Incorporating whole language strategies is a core component to make it real for students that Western scientific knowledge can be constructed and co-constructed in their native language and to truly give a voice and place to their culture in the classroom. Unfortunately, it was not possible to find a single middle school participating in the Mexican National program of innovation in science education with a teacher fully proficient in the students' native language. I was fortunate to have the opportunity to work with the teacher who participated in this study, who lives in and is part of the community (which is uncommon for science teachers working in indigenous middle schools). Despite not being fluent in Nahuatl, she does live and understand the Nahua culture. It follows that whole language strategies are ideal but science teachers who develop a deep knowledge of students' culture are able to successfully enact culturally relevant pedagogies even when limited proficiency in the students' home language.

The second principle that was not fully incorporated in the enactment of the contextualized unit was staff development and pre-service preparation. Although I provided close support to the science teacher participating in this study by observing her class daily and providing feedback, inviting her to observe my class, and having between 1 to 3 planning and debriefing sections per week, this does not replace a pre-service science teaching program where culturally responsive pedagogies are protagonists of the teacher preparation process. Even when pre-service preparation is an issue beyond the scope of this dissertation, it is important to highlight that this contextualized unit would be difficult to enact successfully by most teachers working in indigenous schools in Mexico because most of them do not go through rigorous preparation programs based on culturally relevant pedagogies. Aligned with these structural difficulties, the last principle listed by Klug and Whitfield of coordinating a building-wide strategy for culturally responsive schooling, is definitely beyond the scope of this dissertation. Although this study had the support of the Veracruz State Secretary of Education, and despite my success in working as a team with Spanish language and Math teachers (students worked on reading comprehension strategies to approach a scientific text in the Spanish class and worked on histogram building and interpretation in math class), this was not a school-coordinated effort.

Finally, one limitation of this study already mentioned in the prior section is the absence of an epistemological component that can better support students in navigating multiple ways of knowing. Having exposure to a solid epistemological component, students could have achieved a better understanding that their traditional knowledge has its own epistemology that is not in complete opposition to Western science, thus facilitating border crossing even more. For example, when students learned that two scientists conducted years of research with limited technology in a natural environment (island), taking notes and making observations of animals, they related this story to the way they construct knowledge in their communities, realizing that their cultural practices sometimes overlap with Western science. They connected the methods of field ecology with some of their cultural practices, that is, observing animals and plants to better understand how to use them. This approach allowed students to see the two ways of knowing as complementary. However, not having epistemological knowledge they could not engage in a deeper more meaningful reflection. As I suggested before, the incorporation of an epistemological component in a single contextualized IQWST unit is not feasible or effective, so an epistemological component should be a transversal thread across science concepts during middle school and high school.

To conclude this chapter, I want to highlight that even when this unit was contextualized to be relevant and responsive to one single group of ethnic minority students, it embodied what Pewewardy (2003) describes as education that truly respects diversity. According to Pewewardy, “when schooling provides children with the knowledge, language, and skills to function in the mainstream culture but also honors and provides opportunities for students to learn more about their Native language and culture from elders and others in the community, a true respect for diversity is demonstrated.” In this sense, the principles 4 to 8 can serve as general principles of contextualization for other educational contexts in which teachers and communities are committed to offering students a culturally relevant science education, but do not have the resources to engage in curriculum design from the start. Most marginalized communities do not have the time or financial resources to engage in curriculum design, and therefore, the contextualization principles and experiences presented in this dissertation become applicable to multiple contexts in which is necessary to level the field for marginalized students to access scientific literacy.

CHAPTER 7: CONCLUSIONS

Through this dissertation study, I proposed a process of contextualization to make a biology curricular unit for middle school more culturally relevant for Nahua students in Veracruz, Mexico. In the pages that follow, I will first present the contributions that the findings of this study make to the field of science education, followed by a brief summary of results and implications of the study. I close this chapter by proposing future avenues for research derived from this study.

7.1. What Does it Mean to Contextualize Science in a Culturally Relevant Manner?

Because prior knowledge is the main input for the contextualization process, the first important contribution of this dissertation is pushing the boundaries of how we approach students' prior knowledge. Instead of focusing on prior knowledge being cohesive (Hewson & Hewson, 1983; Treagust & Duit, 2008; Vosniadou, 2002) or fragmented and highly contextual (diSessa, 2006), I propose that cultural cognition, socialization, and cultural narratives play a central role in shaping students' prior knowledge and attitudes towards science (Fig. 7.1). This multifaceted view of prior knowledge presses for gathering multiple and rich sources of information as substrates for the curricular contextualization.

This view of prior knowledge is truly constructivist because it acknowledges the preeminent role of culture and language in learning, and challenges the approaches that define students' prior knowledge solely as what is learned at school in prior years or information students learn through media or family. Those approaches seem incomplete and do not promise to be effective in helping *all* learners to learn. I highlight the word "all" because by not acknowledging the role of culture and language in how students learn, curricula and instruction end up reflecting the worldviews and norms of the designers and teachers, who mostly belong to the majoritarian or empowered groups in society.

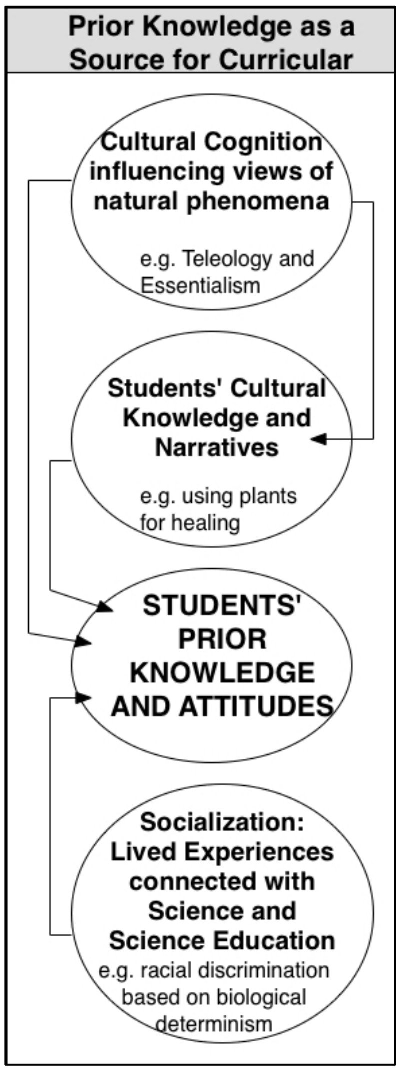


Fig. 7.1. Prior knowledge as conceptualized in this study

Not accounting for the role of cultural cognition, socialization, and cultural narrative when designing curriculum and instruction leaves marginalized students alone in navigating the differences between their culture and home language and the culture and language of school. This divide makes learning more difficult for marginalized students, negatively impacting their self-esteem, and perpetuating the oppression they face. It becomes not only a sound research decision to acknowledge culture and language in science education but also an ethical imperative.

Against this backdrop, this study takes culture and socialization into account by using multiples sources (cognitive tasks, ethnographic observation of students' community, and interviews with students and adults in students' communities) to develop eight principles of contextualization (table 7.1), aligned with the scholarship in Culturally Relevant Pedagogy and Indigenous Education (Agbo, 2004; Barton & Tan, 2010; Cajete, 1994; Castagno & Brayboy, 2008; Ladson-Billings, 2006; Ladson-Billings, 1995; Loving & Ortiz de Montellano, 2003; C. D. Pewewardy, 2003; Sleeter, 2012).

Table 7.1. Empirically developed contextualization principles

Contextualization Principles for Biology Curricula
Using students' culturally based knowledge of living things as a context to understand complex Western science concepts.
Including opportunities for students to reflect on teleological types of reasoning when applied to living things, through the evaluation of inaccurate evidence-based explanations.
Using students' culturally based knowledge of the variability of traits in local plants and animals as a context to understand when essentialism is appropriate in scientific reasoning and when it is not.
Engage adult members of the community in the classroom to share their traditional knowledge and practices as a gateway to explore Western science concepts.
Legitimizing students' traditional narratives and knowledge in the context of the science classroom, thus facilitating border crossing into Western science.
Revaluing students' home language through curricular materials.
Using science knowledge to challenge the status quo and developing critical consciousness.
Including videos as a proxy for storytelling and to support struggling readers.

These principles of contextualization led to the design of activities and scaffolds that were successful in fostering students' learning of complex concepts such as inheritance and natural selection, and can potentially be used to contextualize curricula addressing other core ideas in biology.

The significance of this study, however, lies not only in providing a set of principles and concrete examples for contextualization of science curricula to be used by curriculum designers and teachers. The study's significance also lies in providing research-derived evidence about the effectiveness of these principles to support students whose cultures are not aligned with the culture of Western science to develop healthy cultural identities and sound understanding of science concepts. The potential of learning science as border crossing has been identified by other scholars (Aikenhead, 2001; Bang & Medin, 2010; Costa, 1995; Snively & Corsiglia, 2001), but their analysis has been based on evaluating the alignment of students' culture and perceptions of Western science with the classroom culture and the epistemology of Western science. That is, the analysis is a high-level analysis of students' border crossing from the point of view of the researcher. This dissertation may be one of the first studies in which the border crossing between cultures is documented from the point of view of the students, and in the context of learning specific core concepts of Western science with a contextualized curriculum.

In this sense, presenting empirically derived categories of the types of border crossing students engage in when learning science with a culturally relevant curriculum is a contribution to the field of science education (see Table 7.1). These categories of border crossing can be of great value to science teachers willing to enact culturally relevant pedagogies, as they will have a better idea of the various experiences their students may have and anticipate appropriate strategies to support all student learning.

Table 7.2. Types of border crossing experienced by students.

1	WSK is "better" or provides better explanations than traditional knowledge. This idea is usually derived from internalized oppression (mainstream societal discourses that devalue Nahua knowledge).
2	Traditional knowledge is used only in the community but WSK is used in the city, at school, or for interacting with teachers. Students are not yet thinking of WSK as a type of knowledge they can use in their daily lives or of traditional knowledge as something they can use and share outside of their community.
3	Traditional knowledge can only be built and communicated in Nahuatl while WSK is built and communicated in Spanish only.
4	The student chooses in which contexts to use each type of knowledge for having more efficient communication or serving any other personal goal. This practical approach denotes agency in deciding when and how to use different discourses for one's own benefit.
5	The student sees WSK as useful to understand various aspects of her own culture and believes that traditional knowledge can help scientists better understand the world.
6	The student is able to explain the same phenomenon from the perspective of traditional knowledge as well as from the perspective of WSK without conflict or inaccuracies.

Students who became engaged in the types of border crossing 4 to 6 showed greater cognitive engagement in learning science (as described in the prior chapter): navigating multiple ways of knowing can be proposed as a mediating factor in science learning.

Perhaps the most important contribution of this study is offering an empirically developed and tested process of curricular contextualization (Fig. 7.2) that integrates the experiences of border crossing as mediator factors, the above-mentioned dimensions of students' prior knowledge, and the eight principles of contextualization for biology curricula the proposed here.

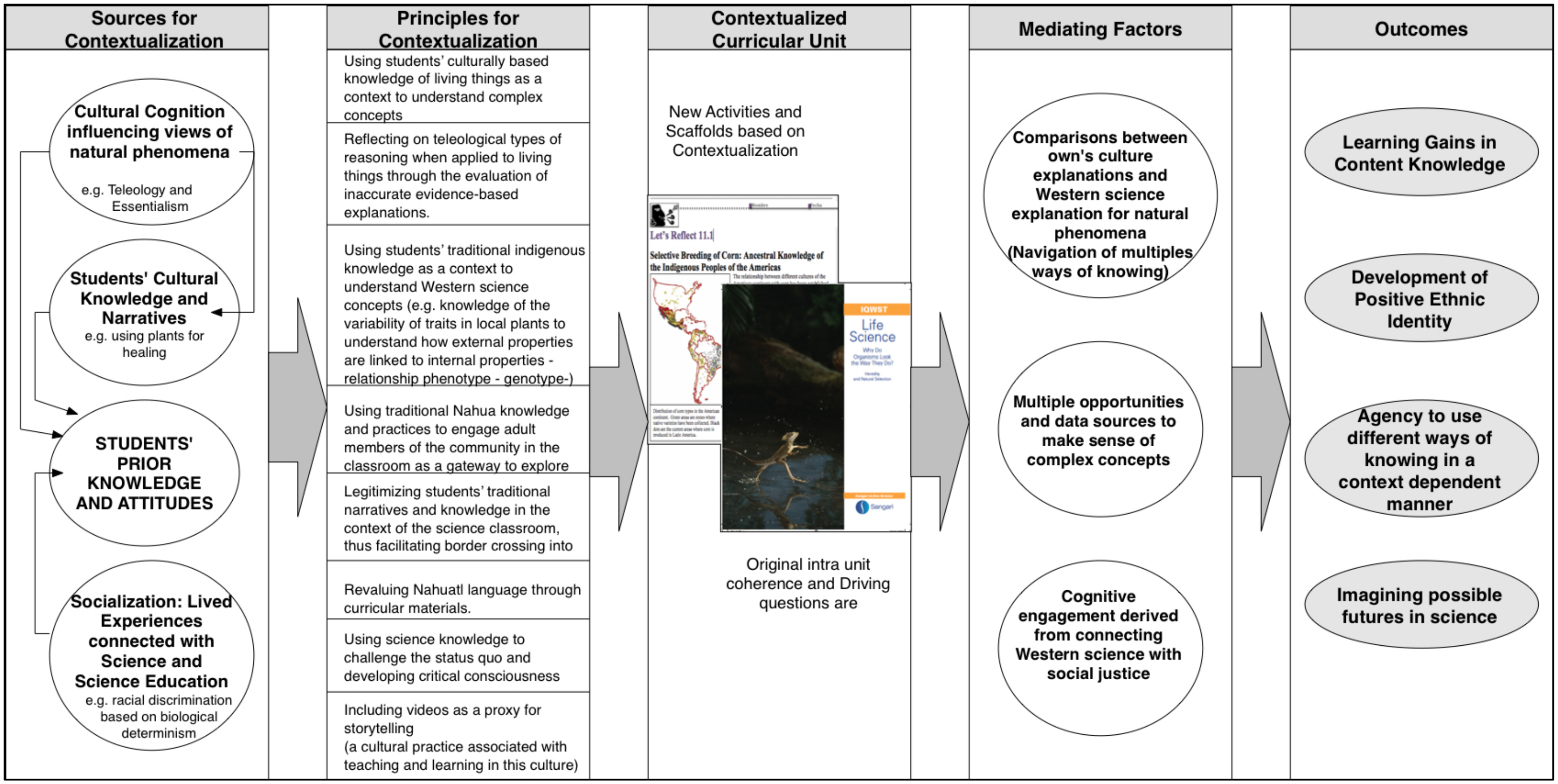


Figure 7.2. Proposed Process of Contextualization with Outcomes

The first mediating factor in the process of contextualization (fig. 7.2) is related with providing students with multiple opportunities and data sources to make sense of complex concepts, facilitating learning gains in content knowledge and engagement in analyzing one phenomenon from multiple perspectives. These opportunities for perspective-taking were crucial to engage students in comparisons between the explanations of their own culture and those of Western science for the same phenomenon, creating a fertile space to learn science as border crossing between cultures. The navigation of multiple ways of knowing was a second mediating factor that facilitated learning by 1) supporting students in using their prior knowledge to make sense of new information, and 2) portraying students' culture as valuable and receiving the same status as Western science. The third observed mediating factor was cognitive engagement, derived of opportunities to use science knowledge to reflect upon or challenge social injustices that students face. The prospect of having the power and knowledge to change an oppressive social reality that they experience was a powerful motivator for students, contributing to their development of a positive ethnic identity while at the same time envisioning possible future careers in science. These three observed mediating factors had important effects in the main four observed outcomes of the contextualized unit enactment: learning gains, development of a positive ethnic identity, agency to use both their own traditional knowledge and Western science knowledge in a context-dependent manner, and imagining possible futures in science.

This process of contextualization is grounded in the community's views, experiences, and needs. My contribution as a researcher was to use my expertise in science education to serve the interests of this community by bringing their views and experiences to the forefront of a science curriculum while ensuring that marginalized students could reach the same (or superior) academic achievement as their privileged peers.

Although this contextualization process is derived from contextualizing a single unit centered in teaching two core science concepts (inheritance and natural selection), it is possible to replicate this approach in other communities and for other core science concepts. Natural selection is one of the most challenging concepts in biology and the fact that this contextualized unit led students to learn makes it worthwhile to test this approach in new contexts where marginalized students have limited access to science education that is relevant for their lives.

The contextualization principles at work in this process reflect a comprehensive understanding of students' prior knowledge. These principles also reflect an understanding of science education as a tool for all students to lead lives they desire as citizens who actively participate in their societies, advocating for social justice (as opposed to science education to prepare youth to be functional workforce in an increasingly technologized world). This understanding of science education makes it imperative to follow a similar process to member checking before enacting the unit, so that wise men and women of the community can see the contextualized unit and evaluate whether it responds to their view of the science education their youth need to break the cycle of oppression (Freire, 1970). Proceeding this way made the process of contextualization consistent with a social justice approach in which students and communities have agency in the educational process, while curriculum designers and researchers put their knowledge to the service of the community through a dialogic process. This dialogue occurring between the researcher and the community, sharing and respecting each other's knowledge, permeated the complete contextualization process and is reflected in the border crossing approach to science learning in the unit. As such, another contribution of this study is that the procedures and aims of research took an approach from the community and for the community, thus contributing to students being successful actors in their communities while gaining tools to succeed in settings dominated by majority culture norms and knowledge (G. Aikenhead, 2001;

Castagno & Brayboy, 2008; Ladson-Billings, 1995, 2006). This perspective allows for students' lived experiences and understandings to become foregrounded and valued as legitimate discourse in the science classroom (Tan & Calabrese-Barton, 2010).

Although this approach to contextualization proved to be successful for the Nahua community of San Pedro de Tequila to become involved in the science education of their youth, an important limitation of this study is the limited inclusion of the Nahua language in the process of contextualization and enactment of the unit. As I described, the Nahuatl language was not present enough in the process of contextualization and enactment of the unit because bilingualism (Spanish/indigenous language) is not enforced or encouraged by the Mexican public educational system beyond elementary school. Lacking structural and institutional support for bilingual science instruction at the middle school level, the suggestions for incorporating bilingualism into science education for indigenous youth (Castagno & Brayboy, 2008) is unrealistic in the current Mexican context. The great difficulty in finding middle school science teachers who are proficient in the Nahuatl language makes it challenging to conduct research studies to compare the effects of enacting a culturally relevant unit bilingually or completely in Nahuatl versus enacting it predominantly in Spanish (a language of colonization). The effects of the eight contextualization principles in a fully bilingual classroom are yet to be explored.

7.2. Teleology and Essentialism in the Context of Culturally Relevant Science Education

I concluded the last section by arguing that fully bilingual science classes in indigenous middle schools in Mexico would be ideal, but given the policies and institutional conditions it is not a realistic scenario. Similarly, when thinking about the expectations we have from students to "think like scientists" the question that comes to mind is whether this expectation is reasonable at the middle school level. Focusing specifically on teleological and essentialist reasoning we find abundant literature documenting how children and lay adults in multiple cultures exhibit teleological and essentialist biases that may interfere with a scientific understanding of the world (Atran, 1998; Bailenson, Shum, Atran, Medin, & Coley, 2002; Casler & Kelemen, 2008; Ferrari & Chi, 1998; Keil, 2003; Kelemen, 1999, 2012; Shtulman & Schulz, 2008), thus judging those individuals as unsophisticated in their thinking. The implicit assumption in this body of literature is that by being enculturated in Western science, individuals abate teleological and essentialist biases and will start thinking more "like scientists."

An important contribution of this study is challenging this assumption. The results of this study show that students can develop a conceptual understanding of natural selection while exhibiting a teleo-functional bias or a systemic-ecological teleology. This finding pushes the field of developmental psychology applied to science education to explore cognitive biases in more depth and beyond a Western-centric perspective. It pushes the field to challenge an understanding of these reasoning patterns as monolithic constructs, in which Western scientific thought is the norm (Gauvain, Beebe, & Zhao, 2011), and study the nuances of teleology and essentialism with the different purposes they serve human cognition in the context of various cultures.

These findings also push science educators and textbook designers to depict scientific reasoning in a more accurate way, therefore not holding students to unrealistic standards. For example, scientists do not show signs of having overcome teleological patterns (Kelemen et al., 2012); it seems unreasonable to expect middle school and high school students to do this. Scientists engage in teleological reasoning when thinking about function-structure relationships, an idea that is one of the pillars of biology and deeply engrained in medical science and drug development. Similarly, without engaging in any form of essentialist reasoning, scientists could not succeed in taxonomic reasoning, necessary to better understand the relationships between organisms, which is ultimately related to understanding diversity and evolution. However, this flexible and highly contextual application of different reasoning patterns is not depicted in textbooks, leading teachers and students to see science as rigid and incompatible with students' cultural resources.

If teleology and essentialism are tendencies of the human mind that help us explain the world and also have a role in Western science, why do we judge it necessary for children and lay adults to overcome these biases to become better able to understand natural selection and evolution? As I mentioned in chapter 6, a hallmark of scientific reasoning might be the sophistication with which scientists decide in which conceptual domains it is appropriate to use teleological and essentialist approaches and in which domains it is unproductive. This nuanced use of these reasoning patterns is gained through deep conceptual knowledge, expertise, and enculturation into specific disciplines of Western science. In other words, professional scientists develop greater metacognitive awareness about what they know, how they come to know it, and when and how to use that knowledge than children, adolescents, and lay adults.

It seems unreasonable to expect that middle school students exhibit this same metacognitive awareness without instruction specifically designed to support its development and with limited conceptual knowledge. What seems more reasonable as a learning outcome for middle school students is to understand what teleology and essentialism are as well as how these types of reasoning are problematic for certain content areas. Of course, this approach demands the revision and practice of these ideas in the context of multiple science disciplines as well as the revision of core concepts throughout the middle school and high school years. This way students can be appropriately supported in their development of an increasingly sophisticated understanding and use of teleological and essentialist reasoning. The goal then would shift from overriding these reasoning patterns to use them with greater and greater sophistication as professional scientists do.

This approach to learning Western science is compatible with learning science in multicultural classrooms and in non-Western settings in large part because fostering the development of metacognitive awareness also helps to facilitate student border crossing between cultures. Students who exhibit teleological and essentialist reasoning patterns that are not aligned with Western science (e.g., religious beliefs or systemic-ecological thinking) would not be held to lower standards or judged as having less science knowledge. On the contrary, they would be equally supported in understanding how different types of teleological and essentialist reasoning can be appropriate in the context of different epistemologies and even within different scientific disciplines. Scaffolding students in order to evaluate scientific explanations that included non-productive teleological and essentialist reasoning was a successful strategy in this study. The continued use of this strategy has the potential to foster the development of metacognitive awareness in the context of specific conceptual domains.

This strategy would work best if it were embedded in a learning trajectory wherein elementary school instruction and activities elicit students' desire-based teleological reasoning so that they can better engage in guided reflection about how that reasoning is problematic when thinking about living things. In the lower elementary grades, need-based teleological reasoning should be acceptable. For example, a shift in understanding from "spider monkeys climb trees because they want to feel safe" to "spider monkeys climb trees because they needs to eat fruits" should be considered as evidence that a student is developing a type of reasoning that will likely lead to more causal-mechanistic explanations later in development if aided by appropriate science instruction (Evans & Rosengren, 2012).

Similarly, in the upper elementary grades and during middle school, students should be scaffolded so that they can understand that self-serving desire-based reasoning is not always appropriate. At the same time, statements such as "spider monkeys climb trees to eat fruits and help trees disperse their seeds" can be understood as an age-appropriate answer that reflects the development of ecological-systemic thinking. Other types of teleological statements that are acceptable at this point of development are those that reflect the development of structure-function reasoning. Using the same example, a teleological statement such as “spider monkeys climb trees because their long arms and prehensile tail are ideal for climbing” should not be considered naïve but as evidence of content knowledge at this stage of development.

During high school and college, students should gain greater conceptual understanding of biological processes and become engaged in sustained reflection and analysis about the fact that other-serving, desire-based reasoning (ecological-systemic) or functional teleological reasoning are not always productive. At this point of development, appropriate tasks for high school and college students include comparing ecological-systemic teleological explanations with completely causal mechanistic explanations such as “monkeys climb trees because they have long arms and prehensile tails that facilitate this activity. Monkeys with those traits have been able to access rich food sources and be safe from predation, thus surviving long enough to reproduce and pass on those traits to the next generation. Monkeys with shorter arms and less prehensile tails would be less likely to survive in the forest environments in which monkeys have lived for over 2 million years.” These students should be able to recognize the explanatory power of a causal statement like this. Of course, crafting a statement like the one presented above requires deep content knowledge that cannot be expected from middle school students. It takes several years of science instruction for adolescents and youth to reach the point that allows them to understand and craft such statements.

Such a learning trajectory finds support in the findings of this study, which demonstrated that students exhibited learning gains in content knowledge about inheritance and natural selection while at the same time exhibiting desire-based/ecological-systemic teleological reasoning, thus building towards a more sophisticated understanding of biological evolution. Accepting ecological-systemic and functional-based types of teleological thinking as mid-points in a learning trajectory that lead towards more accurate and sophisticated reasoning in evolutionary biology has important implications for the education of both rural and non-Western students. The culturally-based reasoning patterns of indigenous students are often judged as "animistic" and incompatible with Western science (Ojalehto, Waxman, & Medin, 2013). Having research-derived evidence that such worldviews do not actually hinder these students' science learning but on the contrary can be valuable resources for learning may help educators to hold views in which such students are understood as thinkers in a progression leading towards more sophisticated scientific reasoning.

Aligned with these findings and conclusions about teleology are similar findings about essentialist reasoning. The results of this dissertation have led me to conclude that, as I suggested earlier, the exhibition of a flexible essentialist bias does not hinder learning gains in content knowledge in the subjects of inheritance and evolution. By flexible essentialist bias I mean that students are more likely to admit potential variability than actual variability in biological species, thus engaging successfully in building population change models and achieving a good understanding of the main principles of natural selection. A full understanding of actual intra-species variability is achieved by means of increased knowledge about the organism or taxa under discussion, which is itself gained through both traditional ecological knowledge and Western knowledge of genetics and population ecology. The aforementioned results to the effect that students did the least essentializing of plants and animal behaviors—the categories in which they have expertise given their agricultural life and traditional knowledge—support this idea. Shtulman and Schulz finding (2008) that adults with the highest evolution comprehension scores were also those adults who essentialized animal properties the least also supports this idea. Therefore, the traditional knowledge of Nahua students concerning plants and animal behaviors can serve as a gateway towards the recognition of actual intra-species variability with which these students may be unfamiliar, thus leveraging an accurate understanding of the Western ideas of natural selection and biological evolution by means of their traditional concepts.

Taking into account that essentialist reasoning plays an important role in categorization, it should not be understood as a reasoning pattern that must be overridden in the path towards developing a good understanding of biology. As middle-school students gain sufficient knowledge of different taxa and species in order to be able to recognize intra-species variability, they become better able to learn what essentialist reasoning is and when it is productive to use this type of reasoning. They can therefore engage in understanding taxonomy and biodiversity as appropriate contexts for using essentialist reasoning while also learning why this reasoning is problematic when understanding genetics, where it leads to inaccurate explanations of biological phenomena such as genetic determinism and in turn creates social problems such as racism and stereotyping. This is another example of how developing metacognitive awareness can help students become more successful in developing a sophisticated understanding of biology.

This approach to developing metacognitive awareness in order to gain the ability to use essentialist and teleological reasoning contextually and flexibly and to thereby develop a better understanding of biological process takes time. A single IQWST unit (about 8 weeks long) unit cannot be effective in fully helping students to achieve this ability. However, science curricula such as IQWST, which has high intra-unit and inter-unit coherence, are ideal for testing the potential for supporting students in the development of metacognitive awareness over time as a tool for facilitating content knowledge gains and better epistemological understanding. Science classrooms where students develop a good understanding of core science concepts and epistemological knowledge become places in which students to engage in the navigation of multiple ways of knowing. They therefore contribute to the education of youth who are highly competent at navigating an increasingly multicultural society.

7.3. Learning Science as Border Crossing Between Cultures Versus Assimilation into the Culture of Western Science

In this study, one key factor for students in experiencing successful border crossing between cultures was the presentation to students that Western science is a culture rather than the source of dogmatic truth. This perspective is valid because Western science has a system of shared meanings and common discourses that scientists use to make sense of the world, thus fulfilling several authors' descriptions of the nature of culture (Geertz, 1974; Hall, 1995; Ngo, 2013). One major implication of the acceptance of Western science as a culture in the context of a pluralistic and democratic society is that science educators have the duty to include a cultural and social dimension in their curricula and instruction. Science educators should teach science as one more culture or one more way of knowing that opens avenues to certain types of knowledge that are of benefit to humanity, not as a discourse to which people from all cultures must assimilate in order to be successful in life. Learning science should not force students to choose between their own cultures and the culture of Western science. The contextualized IQWST unit in this study did not put students in that position, and it thereby better facilitated learning and engagement.

This view of Western science and science education can be beneficial to students of all cultural identities, but it can be especially beneficial to students from marginalized groups because it allows these students do not then see the need to respond to an assimilationist environment by creating an insurmountable cultural border that allows them to maintain pride in their cultural identity (Ngo, 2013). In this study, learning science as border crossing between cultures allowed students to experience their cultural resources as valued in the science classroom, thus making it possible for them to imagine possible futures in science (Barton et al., 2013).

Imagining possible futures in which they can use Western science or even pursue careers in science was important for these students because learning science was not simply a process of acculturation in which they internalized mainstream discourses in order to succeed academically (e.g., obtain high grades). Classrooms in which students have the opportunity to use their cultures and languages as gateways to science learning reduce the chances that family and community expectations will conflict with those of the science classroom. Such a practice thus facilitates the development of a hybrid identity. In the case of this study, the students envisioned futures in which they could be Nahua/indigenous scientists.

Seeing students' cultures as a mediating factor in science learning was the conceptual base for the contextualization principles related to border crossing in this study. Students' traditional narratives and knowledge were used in order to promote learning by building them into the IQWST unit, thus creating opportunities for the students to see that certain aspects of their cultural identity were recognized by science teachers and school as both valuable and important. Developing the proposed activities in the unit that incorporated elements of the Nahua culture allowed the students to position themselves as experts in the science classroom, thereby facilitating their motivation to perform border crossing between cultures as well as their cognitive engagement.

Another aspect that fostered cognitive engagement for the Nahua students was the demonstration that their science knowledge was useful for re-assessing and challenging their experiences of discrimination and oppression. This too increased their interest in science learning and facilitated their participation during science classes. Such an outcome is not surprising because other authors have reported that talking openly about the dynamics of power and privilege in the science classroom has led to engagement for disenfranchised middle school students (Barton et al., 2013). Feature 7 in particular supported students in using their Western science knowledge and knowledge of the life stories of outstanding indigenous individuals to counter fallacious notions of inherited, racialized intelligence.

In general, all of the border-crossing contextualization principles that were incorporated into an already high-quality science curricular unit made up an academically challenging biology unit that was based on Nahua identity and culture, leading these students to outperform comparable 7th graders in the same school with the same teachers (2011 cohort) in the content knowledge test. Interestingly, the Nahua students in this study also outscored the average score of students in the Unites States, who also participated in the field-testing of this IQWST unit. As pointed out before, students in this study showed pride in their culture and were cognitively engaged when they had opportunities to use this culture during science classes, thus improving their understanding of the concepts that they were learning. This fact explains students' test scores better than my proximity to the study, because—although I taught one classroom myself and offered support to the other teacher—I am not part of the Nahua community and was constantly learning from the teacher and the students. Moreover, students in this study had lower pre-test scores than the US average and had never before taken a multiple-choice test. (There are no policies in Mexico such as No Child Left Behind, which makes testing a common school task.) Furthermore, the students in this study were exposed to the scientific explanation concept and scaffolds for the first time in their school life with their experience of this unit, while the US sample had learned with IQWST units at least one time before. These results further support the findings of other studies that academically challenging curricula based on students' identity and culture lead to high academic performance (McCarty, Wallace, Lynch, & Benally, 1991; McCarty, 2012).

In one such example, Hawaiian native students in the Nāwahīokalani`ōpu`u Laboratory school who learned with a college preparatory curriculum that was rooted in native Hawaiian language and culture outperformed students of all ethnicities in English-only schools in the area, achieving rates of 80% college attendance (McCarty, 2012). Similarly, Navajo students in Rock Point School in Arizona learned math and science with a bilingual/bicultural approach and outperformed other Navajo students in English-only schools (McLaughlin, 1995). Despite the fact that these studies are not centered in the enactment of science curricula that support students in their learning of core scientific concepts and practices, they still provide additional context for the results in this dissertation. These results suggests that it was not the consistent support of the researcher that led to high scores, but rather the contextualization principles that were aligned with what other authors have identified as promising practices for the education of ethnic minority and indigenous children and youth (Agbo, 2004; G. Aikenhead, 2001, 2002; Atwater, 2012; Castagno & Brayboy, 2008; Ladson-Billings, 1995, 2006; T. McCarty, 2012; Pewewardy, 2003; Rowland & Atkins, 2003). The inclusion of home language and cultural practices in science curricula goes unquestioned for mainstream Spanish-speaking students in Mexico (or English-speaking students in the US) but is understood as problematic when it is used in connection to the cultures and languages of minority students. This dissertation's results provide prime evidence that the inclusion of students' culture in a high-quality science unit with a border-crossing approach has positive effects in learning gains in content knowledge, cognitive engagement, and the development of a healthy ethnic identity.

The incorporation of students' cultural knowledge and practices in science instruction through a border crossing approach requires curricular units that allow students adequate time to test out their ideas, exchange ideas with their teammates, and work on building evidence-based explanations that include opportunities for students to evaluate multiple sources of evidence (Barton et al., 2013). IQWST fulfills all these characteristics (Krajcik & Sutherland, 2009), which suggests that students can gain understanding of complex concepts such as inheritance and natural selection while at the same time having opportunities to make sense of these concepts from the perspectives of two cultures and by using multiple sources of data. One major implication of the good match between the principles of culturally relevant science education proposed in this dissertation and IQWST is the possibility for the contextualization of other IQWST units. Such contextualized units can become ideal materials for the teaching of science in multicultural classrooms not only in Mexico but in the US, a country with increasingly multicultural classrooms and a pronounced decline in students' interest to pursue science.

7.4. Further Implications and Final Comments

The results of this dissertation should not be interpreted as feasible solely in a "culturally homogenous" classroom and as therefore difficult to achieve in multicultural classrooms. Such a claim essentializes indigenous students' culture by not recognizing the great diversity in learning styles, interests, degrees of bilingualism, and enculturation into the mainstream culture that these students experience. A Nahua indigenous classroom can be as diverse as an inner city classroom in a large US city for a number of reasons: 1) the Nahuatl language has different dialects and variants, and it is difficult for a science teacher to be fully proficient in all the Nahuatl dialects; 2) students' command of and particular accents in Spanish may show a wide variability in single classroom; 3) the tensions between communities' efforts to maintain cultural pride and the overtly discriminatory discourses of mainstream Mexican society lead students to adopt a wide range of positions, from the rejection of their own culture and language to dropping out of school during middle school because they believe that it is better to help their families than to experience discrimination at school; and 4) migration and mobility of families to the US and back to Mexico creates situations in which students were schooled in English for some years, speak Nahuatl at home, and are now receiving instruction in Spanish. These are common scenarios in indigenous middle schools in Mexico. Students who are representative of all of the above-mentioned situations were present in the two classrooms where this study was conducted. The fact that the principles of contextualization presented in this dissertation led to the creation of activities and scaffolds that moved students to learn science in this complex context makes them promising for the contextualization of other science units in the indigenous and multicultural classrooms of Latin America and North America.

Living in a multicultural society demand that citizens develop special competencies such as the ability to understand and respect multiple cultures and the ability to navigate multiple ways of knowing (Aikenhead, 2001; Rowland & Atkins, 2003). These competencies are crucial for ethnic minority students if they are to become active participants in their communities and in mainstream society; they are also crucial for privileged students (because of SES, race, ethnicity, or nationality) if they are to become productive contributors in the construction of a more just society. Against this backdrop, science education has an important role to play in the education of children and youth and the creation of future citizens who are able to navigate multiple cultures and ways of knowing while remaining proud of their own ethnic identities and achieving scientific literacy.

Learning science as the one and only valid way to explain the world has many potential negative effects. First, it is dismissive of all other cultures in the world that have developed their own epistemologies across centuries or even millennia. In this sense, the message sent to students is that certain cultures are "right" and others are "wrong." This certainly does not contribute to a more just society within which diversity is understood as an asset and not as a problem to be "dealt with." Second, having Western science knowledge as the only valid way of knowing alienates all students whose cultures are not aligned with Western science (Aikenhead, 2001; G. Aikenhead, 2002; Bang & Medin, 2010; Barton & Tan, 2010), forcing these students to assimilate to a foreign culture and therefore hindering their motivation to pursue future careers in science. Finally, by presenting Western science as superior to students' culturally-based ways of knowing, science education contributes the injured self-esteem of children and youth, thereby increasing their chances of low academic achievement (Hope, Chavous, Jagers, & Sellers, 2013). These are powerful reasons that pushed this study in the direction of finding ways in which students could become scientifically literate without having to choose between Western science and their own cultures. A border-crossing approach to learning science seemed promising for the achievement of this goal, and the results of this dissertation support the use of such an approach as one way to support students in successfully making sense of complex concepts in Western science. The results of this dissertation confirm that Culturally Relevant Science Education is a promising approach for allowing access to science to minority groups that currently experience educational inequality, among many other consequences of colonization, racism, and classism.

Indigenous peoples, the African diaspora, and some communities of Latinos in the southern US are involuntary minorities. It is our responsibility as educators in a democratic society to contribute to their cultural survival (after centuries of colonization and cultural genocide) while ensuring that they have access to education that ensures them equal access to opportunities and participation in the societies in which they live. In an increasingly technologized world, quality science education is a key factor for producing citizen participation in socio-scientific debates that affect citizens' quality of life and access to job opportunities. It is therefore urgent to incorporate cultural relevant approaches to pedagogy into science education.

As necessary as Culturally Relevant Science Education is for Nahua students in Mexico, it is similarly necesary for students who belong to other marginalized groups. Accounting for the cultures of these students and increasing student engagement in learning and self-esteem can lead to improvements in academic achievement. The inclusion of traditional indigenous knowledge as well as the ways of knowing of other cultures in the science classroom can help all students to gain insight into how they might best navigate multiple epistemologies and go beyond dogmatic views of science in order to achieve a reflexive/critical view that fosters respect for all cultures and languages. One result of this type of education is the formation of future citizens who are responsible participants within culturally diverse societies that work to preserve all cultural identities. This is certainly compatible with democratic principles and is furthermore necessary if we are to build a more egalitarian society.

However, designing and enacting materials that are culturally relevant for students requires intensive work in and understanding of content knowledge, and most of the responsibility for the design and enactment of such materials is left to teachers who often find themselves overwhelmed by this task (McCarty, 2013). According to Loving and Ortiz de Montellano (2003), "there is a great demand for approaches that tie culture with science, and the refusal of scientists and science educators to develop accurate and valid materials of this type has fostered the development of alternative science materials of dubious quality and their adoption by school districts with large minority enrollments." This is of course a disservice to marginalized students who thus see their opportunity for quality science education further reduced. Against this backdrop, it is the responsibility of the community of educational researchers to provide teachers with the tools to enact culturally relevant pedagogies by investigating the best ways to design and enact culturally relevant materials and making them widely available. This dissertation is a direct response to this responsibility.

Finally, although a grassroots approach to curriculum development would be ideal for the development of science curricula that strongly incorporate students' language and culture, this is a costly route in terms of time and financial and human resources, especially in impoverished school districts or indigenous schools that receive limited resources, which is where the greatest need for culturally relevant approaches exists. Therefore, the thoughtful contextualization of already validated high-quality science curricula that follow the process proposed in this dissertation is a more viable option for the provision of access to science literacy to all students, regardless of ethnicity, language, or place of origin. The process of contextualization proposed in this dissertation creates opportunities for teachers and students to believe that all cultures are capable of doing science. In short, this is a real path toward achieving "science for all."

8.6. Outstanding Questions Derived from this Study

Future avenues for research might involve the transformation of the process of contextualization as proposed in this study into a model for contextualization. In order to produce such a model, a larger sample and multiple settings would be necessary, as well as the development of measures for the constructs and outcomes that would be presented in the process. One pertinent methodological approach for the development of such a model and for understanding the directionality and relationships between constructs is structural equation modeling.

In terms of the inclusion of culture into science education, several outstanding questions arise from this study:

- How do differences in cultural cognition affect the positioning of students along learning trajectories?

- Is the border crossing approach appropriate for teaching and learning other science core ideas?
- What are the implications of a border crossing approach for the learning of science in terms of self-determination, cultural preservation, and activism?
- Can the contextualization principles proposed here be used to evaluate curricular materials?

It is my hope that the community of researchers in science education becomes further interested in investigating these questions so that we can together contribute to the building of a more just society where all students, including those who are disenfranchised, receive the benefits of quality science education. It is certainly my goal to make these questions the central part of my future research agenda.

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