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INTRODUCTION

"Why would there be iron in the water near the confluence of the spring and the river?" asked one of DeVore-Wedding's students. The student had just learned how to test for iron ions in water in her chemistry lab and decided to test water samples she had collected along a local stream. The stream flowed from an artesian spring into the local river. The two upstream samples did not contain iron while the third sample at the mouth of the stream tested positive. To answer her own question, the student set out to learn more information about the spring and its surroundings. The next week, this student arrived in class not only with answers but excited about her new project! She had discovered a rusted car hood upstream from the iron-rich water sample. The student's observations about her environment provided more information than three isolated water samples could ever provide. Even more so, through her research, she discovered that the artesian spring was once an important water source for the community prior to the arrival of the municipal water supply. Her subsequent project to clean up the spring and restore it to a more natural state provided a public service component while connecting her to a place of importance for the tribal community. In addition, this student integrated her chemistry lab experiment with results from her ecology course. Furthermore, her eyes were opened to a career path in environmental science, which turned

into an internship with the tribe's environmental protection department. This student's story exemplifies our rationale for indigenizing the chemistry curriculum at Nebraska Indian Community College (NICC) and Little Priest Tribal College (LPTC) as part of a National Science Foundation–funded collaboration between these two tribal colleges and the University of Nebraska–Lincoln (UNL).

There are now many ways to indigenize science courses at tribal colleges and universities (TCUs). This is happening just after the American Indian Higher Education Consortium (AIHEC) celebrated its forty-fifth anniversary (Braithwaite 2007; Crazy Bull 2012), which suggests a maturation of ideas planted several decades earlier. The members of AIHEC compose the thirty-eight accredited TCUs, whose goals are to strengthen tribal nations and to make a lasting difference in the lives of American Indians and Alaska Natives (AIHEC 2000).

Scientific inquiry that includes Indigenous knowledge or Native ways of knowing is called ethnoscience (Davison and Miller 1998; Deloria 1992; Nelson-Barber and Estrin 1995). Ethnoscience brings the content alive by connecting to the tribal culture (Gruenwald 2003; Johnson 2012; Nicholas-Figueroa et al. 2017). Cultural connection engages Native American students because it relates to their prior knowledge, their cultural history, and their everyday lives (Mack et al. 2012; Semken and Freeman 2008). Student histories of place and being within the tribe provide a wealth of knowledge that makes science learning authentic (Johnson 2012). It also connects their new knowledge to their constellation of cultural connections in a way that is more likely to help them bring that new knowledge into their community (Aikenhead 1997; Cajete 1994).

Informal and place-based instruction provides experiential learning that complements Indigenous and community knowledge (Brayboy and Castagno 2008; Semken 2005; Semken and Freeman 2008). This connection to traditional teachings of community and tribe is the norm at tribal colleges because their mission is to offer culturally responsive and relevant learning opportunities (Brayboy and Castagno 2008; Talahongva 2018). For example, the Hopi biologist Frank Dukepoo stated, "Elements of cultural knowledge do not create barriers in the study of science, but rather can enhance, excite, and stimulate scientific curiosity and inquiry" (Nelson-Barber and Estrin 1995, 4). Likewise, David A. Gruenwald (2008, 147) sums up this teaching style by saying, "Each one of us is a product of a lifetime of environmental and cultural education that includes our embodied experience of places." Finally, Martha Austin-Garrison, who grew up speaking Navajo but did not learn to read or write it until her college years, says that she blends both the native language and culture of her students based on the universal concept of the mind, body, and spirit common to tribes in the premedical courses she teaches (Talahongva 2018).

Gregory Cajete (1999) synthesized these philosophical points into a model in which Native American students were served through a culturally responsive science curriculum that integrates Native American traditional values, teaching principles, and concepts of nature with modern Western science. Even so, there are some interesting connections that need to be considered when integrating tribal history, language, and culture with science course content, including (1) hiring a science instructor based on content expertise but who may not be familiar with tribal culture; (2) enrolling students from diverse tribal cultures; and (3) teaching the course material described in the syllabus so that the credit is transferrable to other tribal and nontribal colleges and universities. Each must be seriously considered before the first day of the course. In this respect, Cajete (1999, 82) offers a way for the instructors, students, and institutions to merge their interests when he writes that "Indigenous science honors the essential importance of direct experience, interconnectedness, relationship, holism, quality and value . . . to gain a deeper understanding of natural relationships." That is, the instructor can offer the traditional science content while engaging students in discussions about their unique perspectives and while meeting the institutional goals of student-centered learning of the content. When all of this comes together, Cajete (1999) says that you will ignite the intellectual sparkle in your students' eyes. In this review, we describe the successful strategies that have been used by several tribal colleges and universities to indigenize their science courses, after-school programs, or research efforts on their path to igniting Cajete's sparkle.

CHEMISTRY LAB COURSE AT TURTLE MOUNTAIN COMMUNITY COLLEGE

Turtle Mountain Community College (TMCC) was among the first to indigenize their science curriculum, which in their case was the second semester of a chemistry lab course. TMCC is located in Belcourt, North Dakota, in north central North Dakota, a mere ten miles from the Canadian border. TMCC serves the Turtle Mountain Chippewa Tribe with an enrollment of approximately 970 students. TMCC offers several chemistry courses: Survey of Chemistry, Introductory Chemistry, Introduction to Organic and Biochemistry, a two-semester sequence of General Chemistry, Organic Chemistry, Biochemistry, Forensic Chemistry, Environmental Chemistry, and Analytical Chemistry, all with labs included. Other science courses offered by TMCC are Astronomy, Meteorology, General Biology I and II, Human Structure and Function, Agronomy, Research Methods, Environmental Science, Zoology, Microbiology, Anatomy and Physiology I and II, Ecology, Entomology, Environmental Geology, Physical Geology, Historical Geology, College Physics I and II, University Physics I and II, Planetary

Science, and Physical Science for Teachers. TMCC also offers Introduction to Engineering, Statistics, and Dynamics.

From 2002 to 2004, TMCC had a grant from a National Institutes of Health to design lab experiments that would make chemistry "more interesting and relevant to Native American students" (NIH Grant 1R25GM066064). Other North Dakota colleges that participated in this grant were Cankdeska Cikana Community College, Fort Berthold Community College (now Nueta Hidatsa Sahnish College), Lake Region State College, North Dakota State University, Sitting Bull College, and United Tribes Technical College. The project began with a field tour to collect culturally relevant plants led by Charmane Disrud, a faculty member at TMCC ("RISE" 2002). One month later, Gary Stolzenberg, a chemistry faculty member at North Dakota State University led a four-day workshop in which fifteen tribal college faculty and students learned how to separate and analyze the plant materials. The experimental protocols were further developed by Mikhail Bobylev at Minot State University. Disrud wrote the lab manual, including the background information and lab report questions.

The result of their effort was a new chemistry lab manual (see the list titled "Organic and Biochemistry Experiments Chapter Titles"; Turtle Mountain Community College 2006) called RISE (Research Initiative for Scientific Enhancement). Although the experiments were developed for the North Dakota tribal colleges, the approach was broadly interesting, and the manual was soon adopted by other tribal colleges. For instance, both Little Priest Tribal College and Nebraska Indian Community College possessed the *Organic and Biochemistry TMCC Lab Manual* when they began their collaboration with the University of Nebraska–Lincoln in 2012, and it had an influence on that collaboration.

ORGANIC AND BIOCHEMISTRY EXPERIMENTS CHAPTER TITLES[1]

1. Indicators (Berry Juice Extracts as pH Indicators)
2. Dying of Quills with Natural Plant Extracts
3. Pigments in Plants Used by American Indians in North Dakota (Solid Phase Extraction and Chrmomatography)
4. Qualitative Tests for Alcohols
5. Effect of Alcohol on Cell Membranes (Damage to Plant Membranes by Alcohol, Heat, Detergents, and pH as Measured by Spectrophotometer)
6. Phenolic Content and Antioxidants
7. Ascorbic Acid Content in Traditional Native American Foods (Quantitative Measurement of Vitamin C in Foods)
8. Preparation and Identification of Esters

9. Synthesis of Aspirin
10. Preparation of Linoloyl Acetate (Sage Odor)
11. The Science of Making Soap (and Comparison to Detergents)
12. Saponins in Yucca Plant Roots
13. Steam Distillation of White Cedar (or Wild Mint, to Isolate the Fragrant Oil)
14. Extraction of Caffeine from Yerba Maté
15. Isolation of Casein and Lactose from Milk

The first TMCC chemistry experiment, number 1, "Indicators," uses berry extracts as pH indicators. The protocol requires the students to extract colored compounds from a selection of June berries, chokecherries, rosehips, plums, wild raspberries, willow bark, onion skins, mint, and plant blossoms. Then, the color changes are compared with commercial pH indicators, such as litmus paper and phenolphthalein. The introduction describes a cultural connection in that wild plants were used for dying quills and leather in addition to being used for food and medicine. Furthermore, it was proposed that American Indians may have observed these color changes while extracting and working with the dyes.

Another experiment, number 13, involves extracting a fragrant organic oil from white cedar or wild mint. The cultural connection is that American Indians use those plants in sweat lodges and that wild mint is made into a medicinal tea. The introduction concludes by giving the French-Cree and Chippewa words for wild mint leaves.

EXTRACURRICULAR BIOLOGY RESEARCH AT IḷISAĠVIK COLLEGE

We start our summary of ongoing programs with Iḷisaġvik College, which is developing a research experience outside the classroom with a goal of increasing student interest in taking more science courses. Informal science education allows students to explore science in a way that is meaningful to them, which leads to deeper understanding and stronger commitment to science (NRC 2009; Mack et al. 2012).

Iḷisaġvik College is the only tribally controlled college in Alaska and is the northernmost accredited community college in the United States. It is located in the village of Utqiaġvik (formerly known as Barrow) about five hundred miles from the closest university. The eight villages served by the college are on the North Slope of Alaska and are only accessible by airplane. Iḷisaġvik College serves approximately 288 students of the Iñupiat Tribe—North Slope Borough, Alaska. They offer a Chemistry and Society course, Basic Chemistry, and Survey of Organic and Biochemistry. They offer a traditional menu of biology courses: Human Biology, Biology and Society, Fundamentals of

Biology I and II, Human Anatomy and Physiology I and II, Introductory Microbiology, as well as Natural History of Alaska. An individualized research project course is available as well. Labs are included in all the courses. An Introduction to Earth Science and Indigenous Sciences and Traditional Ecological Knowledge with labs are offered in the geosciences category. A Topics in Modern Science course is also available in both biology and geosciences. The health science and fire science programs offer several courses, including Hydraulics and Water Supply, Hazardous Materials Chemistry I, Introduction to Pathology, Introduction to Pharmacology, and Introduction to Nutrition.

Starting in 2016, Linda Nicholas-Figueroa at Iḷisaġvik College began a research project funded by the National Science Foundation (NSF) (Grant 1622418) titled "Arctic Microbes: Population Abundance and the Effects on a Warming Environment." The rationale was that many of the undergraduate students from these rural villages are rarely exposed to the many research activities that take place across the North Slope. The specific goal of this project is to investigate whether rising temperatures will alter microbial populations that could lead to a cascade of events ultimately affecting arctic vegetation and animals and thus the subsistence diet of people in the Arctic. Students gather samples in the field and then analyze them at the bench while learning microbiology, genetics, and molecular biology. For example, students in the microbiology course could easily grasp the topic of microbial genetics, nutrition, and growth. While these topics are important, this means they do not learn about the research concerning animal migrations, whale feeding patterns, and changing sea-ice conditions (Nicholas-Figueroa et al. 2017), all of which are important community topics. Through place-based instruction, students visit research sites and learn science concepts by interacting with scientists. For instance, as a whaling community, students in a biology course visited the North Slope Borough Department of Wildlife Biology to observe a bowhead whale lung and discuss with the scientists lung-volume respiration rates that are important in determining the bowhead's energetics and feeding patterns. They later determined their own lung-volume respiration rates with a better understanding of respiratory physiology from the site visit.

Equally important, students learn the significance of their research as it relates to the local environment and the community. Such experiences lead to critical thinking skills that promote lifelong learners, thereby engaging the students in real-world issues that have relevance to their lives. Indigenous knowledge, informal, and place-based science education can encourage students to pursue careers in science, technology, engineering, math, and health-related fields or to become informed leaders and decision makers in their communities.

Nicholas-Figueroa continues to incorporate Indigenous knowledge in her Chemistry and Society lab. For example, she has tied

the extraction of oils from native plants to organic compounds. The extraction of oils from native plants is likewise used in the investigation of their antimicrobial properties in her Indigenous Science and Traditional Ecological Knowledge lab.

MEDICINAL PLANTS STUDENT PROJECT AT UNITED TRIBES TECHNICAL COLLEGE

United Tribes Technical College (UTTC) recently completed an extracurricular project in which students helped assemble a workbook of medicinal plants found in North Dakota. UTTC is located in Bismarck, the capital of North Dakota and its second most populous city. UTTC enrollment includes approximately six hundred students from at least fifteen tribes in sixteen states, which increases the potential for diverse cultural connections. UTTC is directly associated with the affiliated tribes of Fort Berthold, the Spirit Lake Tribe, the Sisseton-Wahpeton Oyate, the Standing Rock Sioux Tribe, and the Turtle Mountain Band of Chippewa Indians.

The UTTC chemistry courses include General Chemistry I and II and Organic and Biochemistry, all with labs. Additional science courses with labs include Anatomy and Physiology I and II, Earth Science, Environmental Research, General Biology I and II, Medical Microbiology, and Physical Science. Those courses without a lab included are Cellular Biology, College Physics, Ecology, Environmental Research Project Seminar, Environmental Seminar, Introduction to Range Managements, Introduction to Scientific Literature, Physical Geology, Physical Geography, University Physics I and II, and Introduction to Engineering, Statics, and Dynamics

Recently, faculty and students at UTTC assembled a workbook of North Dakota medicinal plants. The workbook was accompanied by teacher and student manuals. This project was a collaboration with the Global Institute for BioExploration (GIBEX), which seeks to promote "ethical, natural product-based pharmacological bio-exploration to benefit human health and the environment in developing countries (GIBEX 2021)." GIBEX was founded by Rutgers University and the University of Illinois at Urbana-Champaign and now includes North Carolina State University and both campuses of the University of Alaska.

In the chemistry courses, Paul Pansegrau has begun to incorporate examples from the environment and nature. For example, prior to the lab where students synthesize aspirin, the students learn that willow bark was chewed for its analgesic properties as it contains salicylic acid. Another organic chemistry example is that the piping plover is ultrasensitive to polyaromatic hydrocarbons (PAHs). A biochemistry example relates to glycogen storage and the scene from the movie *The*

Revenant (2015) in which an unnamed Native American fellow (played by Arthur Redcloud) and Hugh Glass (played by Leonardo DiCaprio) consume raw bison liver together. Watching this interaction caused students to reconsider the movie with a biochemistry lens for accuracy. In the lab session where students synthesize alum, its use as a tanning agent for leather production is discussed and compared to the more environmentally friendly Native American leather production methods.

SCIENCE-COMMUNITY CONNECTIONS AT NEBRASKA'S TWO TRIBAL COLLEGES

Nebraska Indian Community College (NICC), Little Priest Tribal College (LPTC), and the University of Nebraska–Lincoln (UNL) developed a new method by which any tribal college could connect science lab experiences to tribal community topics (Griep et al. 2016). Both tribal colleges are located in the northeastern part of the state, while UNL is located 120 miles of highway driving away in southeastern Nebraska. NICC serves approximately 177 students at three locations using a synchronous distance learning system. NICC serves the Omaha Tribe at the Macy campus, the Santee Sioux Nation at the Santee campus, and maintains a third campus in downtown South Sioux City. This grant allowed NICC to create and offer three chemistry courses: Pre-Chemistry, Introductory Chemistry, and Organic and Biochemistry. This year, they added a Chemistry Research course. NICC also offers Anatomy and Physiology, Biology, Botany, Ecology, Environmental Science, Geology, Natural Sciences, Physical Science, Special Topics, and internships. Labs are offered for all of the specific content science courses.

LPTC serves approximately 148 students on their campus and is governed by the Winnebago Tribe. They offer a two-semester sequence of General Chemistry and Organic and Biochemistry with included labs. Their other science lab courses are General Biology, First Aid and Cardiopulmonary Resuscitation, Earth Science, Environmental Science, Human Anatomy and Physiology I, Human Anatomy and Physiology II, Nutrition, Microbiology, Indigenous Plant Science, Physical Science, and Soil Science.

The NSF-funded collaboration has been ongoing for five years and just produced a *Tribal College Chemistry Lab Manual* (Griep et al. 2018). A range of indigenizing methods are used in nearly all experiments, including student discussions about tribal community topics, a prayer to give thanks for the bounty that allows us to have enough materials that we can sacrifice some for use in the experiment, and using materials of relevance to the local tribes. At the beginning of each experiment, students are asked to reflect on how the experiment they are about to perform is relevant to their lives. To bring some context to

their thoughts, they are provided with a list of tribal community topics (see the list titled "Tribal Community Topics"; Griep et al. 2016; 2018) that were identified by the grant's advisory board before the first course was even taught. The board generated a list of topics that are needed to maintain or enhance tribal sovereignty. The board's list is not solely focused on its use by science courses because they were asked to think broadly about maintaining sovereignty. To personalize the discussions, the pre-lab discussions are not restricted to the list of community topics but can include students' personal histories or their culture's histories. Students are requested to include a short summary of their thoughts about these connections in their lab reports, although this is not part of their lab report grade. Since there are so many experiments that involve water chemistry, a chemistry community connection titled "Life Flows: Connecting Chemistry to Water" was written with questions that prompt students to make water connections to agriculture, food sovereignty, soil quality, and water quality.

TRIBAL COMMUNITY TOPICS[2]

Air Quality
Animal Habitat
Bio-piracy
Climate Change (Trends, Historical Knowledge, Ecosystems)
Community Health (Food sources, Genetics, GMOs)
Disease
Economic Development Issues (Trust Lands, Environmental Racism)
Food Sovereignty
Medicinal Plants (will not be used for experimentation without tribal council permission)
Natural Resources (Soil, Land)
Oral Histories (will not be published without tribal council permission)
Ownership/Stewardship
Renewable Energy (Solar, Wind, Compressed Wood Pellets)
Waste (Solids, Land Fills, Hazardous)
Water Sources (Metals, Natural Disasters, Policy, Remediation Programs, Testing, Watersheds)

Nearly all of the twenty-five experiments in the *Tribal College Chemistry Lab Manual* (see the list titled "First Semester Chemistry Experiments"; Griep et al. 2018) make use of the Ethnoscience method in which the materials have relevance to the agriculturally oriented Missouri River tribes. For example, the introduction to experiment

number 2, "Density," explains that squash seeds, bean seeds, and corn kernels are used because they encompass the Three Sisters gardening practice of planting them together in a single mound (Landon 2008). Pedagogically, the three seeds make a nice set for measuring density because they have distinctly different shapes. This early discussion sets the stage for making future connections to agriculture, water, and soil. Since the seeds and beans cannot be used after they've been handled, a brief prayer has been included that acknowledges their sacrifice on our behalf: "We are thankful for the bounty of food that we are able to use the corn, beans, and squash seeds in this lab." The prayer is located at the beginning of the "Protocol" section so that students read it right before beginning their work. The science concepts in experiment 2 are foundational chemical concepts, such as how to measure mass and volume, the need for multiple measurements, and the importance of accuracy and precision. The choice of materials introduces such concepts as the difference between bulk seed density and true seed density, how to measure the density of irregularly shaped objects, and the individuality (or nonuniformity) of biological specimens. To enhance learning even further, most experiments adopt an inquiry approach because a great deal of evidence has shown it makes the experience engaging for students and instructors alike (Minner, Levy, and Century 2010; NRC 1996; 2000; 2012; Rissing and Cogan 2009). In the case of experiment 2, this means that students are given a selection of seeds and beans from which they must choose at least two for their measurements. The result is that each student's set of measurements is unique, which helps them see that each bean or seed has characteristic properties. This personal connection to the materials and measurements provides a scaffold for students to describe and explain their results in their lab reports. To further increase students' connections, they are encouraged to include a paragraph summary in their reports of their main conclusion in their native language. Instructors who teach the course for multiple years will complete the learning cycle when they read the lab reports and learn the student perspectives about their cultural community connections.

FIRST SEMESTER CHEMISTRY EXPERIMENTS[3]

1. Safety, Equipment, and Measurement
2. Density
3. Chocolate Density
4. Liquid Density
5. Periodic Table of Videos
6. Water Quality Analysis

Proposal for End of First Semester Project

7. Water Purification
8. Soil Quality Analysis

9. Herbicide Bioassay
10. Plant Pigments: Extraction, Chromatography, and Spectrometry
11. Endothermic and Exothermic Reactions—Hot and Cold Packs
12. Molar Mass of Butane in Lighters
13. First Semester Creative Project and Presentation

SUMMARY

Over the past two decades, the tribal college science projects described in this review have ignited the sparkle in many students' eyes. These funded projects have built on Cajete's (1999) call for ethnoscience approaches to deepen the student learning experience.

The *Turtle Mountain Community College Chemistry Lab Manual* established the pathway that the others have followed in their formal science courses. They encouraged the analysis of materials with tribal importance and provided introductory summaries that explained the context of those materials. Iḷisaġvik College and United Tribes Technical College took a broader approach by developing informal learning experiences. A strong advantage of informal experiences is the ability to relate science content to tribal ecological knowledge, as well as history, language, and culture (Mack et al. 2012). This approach has been shown to increase student interest in both science and tribal culture.

The indigenizing approach developed by Nebraska's two tribal colleges allows each year's student cohort to connect their life experiences to the content. Native ways of knowing reveal the myriad connections found in nature that provides a thought-provoking counterpoint to science's reductive ways of knowing. The Nebraska method is highly adaptable, requiring only an instructor who is able to encourage students to share their knowledge as it relates to the course content. This promotes an environment for authentic, real-world learning, which engages and motivates students' interest in content and its applications (Cajete 1999; Mack et al. 2012).

AUTHOR BIOGRAPHIES

Beverly R. DeVore-Wedding is an Assistant Professor in the School of Education at Adams State University in Alamosa, CO. She was a post-doctorate in the Department of Chemistry at the University of Nebraska-Lincoln, where she provided sustainable chemistry and indigenized lab experiences. Prior to that, she taught high school place- and project-based science and mathematics for 28 years. She was

awarded the Colorado Association of Science Teachers' high school science teacher of the year in 2011.

Linda Nicholas-Figueroa is an Associate Professor of Biology and Chemistry at Iḷisaġvik College in Utqiaġvik, AK. Her work is on engaging Alaska Native and rural Alaskans in STEM through place-based and informal education.

Paul Pansegrau is a part-time instructor in the Department of Chemistry at the University of North Dakota in Grand Forks, ND. When this manuscript was being prepared, he was a chemistry instructor at United Tribes Technical College in Bismarck, ND.

Janyce Woodard is Director of Equity and Extension at Little Priest Tribal College in Winnebago, NE. When this manuscript was being prepared, she was an instructor of Indigenous Science at Little Priest Tribal College.

Hank Miller is the Math & Science Division head and Director of Natural Resources at Nebraska Indian Community College, Santee campus, in Macy, NE. Besides teaching, his work has centered on environmental and human health, with funds secured from AIHEC, EPA, NASA, NFS, NRC, USDA, and Van Flack grants, while nurturing collaborations and partnerships with others.

Mark A. Griep is a Professor of Chemistry at the University of Nebraska–Lincoln. His lab studies the enzymology of lagging strand DNA replication. His partnership with Nebraska's two tribal colleges is focused on increasing their science courses and outreach activities in ways that enhance tribal sovereignty.

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NOTES

1 From Turtle Mountain Community College 2006.

2 From Mark A. Griep, Beverly R. DeVore-Wedding, Janyce Woodard, and Hank Miller, "The Sharing Cycle of Science Learning: Connecting Community Topics to Tribal College Lab Courses," 2016.

3 From Mark A. Griep, Beverly R. DeVore-Wedding, Janyce Woodard, and Hank Miller, *Lab Manual for Connecting Chemistry to the Tribal Community: Two Semesters of Chemistry Experiments and Teachings*, 2018.