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Tipi Fluid Mechanics: Indigenous Perspectives & Essential Understandings in Engineering Education

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ABSTRACT

CONTEXT

Indigenous people have been engineering sustainable, resilient solutions informed by diverse peoples, places, and processes since time immemorial. There is much to learn and share from the stories and structures of the nomadic Plains tribes' traditional homes (lodges/tipis/teepees), however, tipis have not yet been studied from an engineering perspective nor incorporated into engineering coursework. Guided by a unique state constitutional article, Montana's Indian Education for All (IEFA) Act, and the ensuing seven Essential Understandings regarding Montana Indians, faculty in education and engineering at Montana State University have sought to implement then improve culturally responsive activities in engineering coursework.

PURPOSE OR GOAL

Indigenous perspectives and essential understandings were introduced via tipi pedagogy through a guest lecture and outdoor tipi-building activities in the spring of 2023 within a second-year engineering fluid mechanics course. While successful in engaging students, there was an apparent lack of connection to the course objectives and learning outcomes. This study's specific aim was to demonstrate that Indigenous perspectives and IEFA Essential understandings can be introduced *without* compromising the course learning objectives or learning outcomes.

APPROACH OR METHODS/METHODOLOGIES

In response to informal student survey responses from the pilot effort in 2023, the co-authors designed an expanded, two-day tipi fluid mechanics workshop grounded in both relational, Indigenous Methodologies and experiential, High-Impact Educational Practices within a second-year engineering fluid mechanics course. Students were divided into working groups across two-day workshops led by Indigenous facilitators in classroom, laboratory, and outdoor settings.

ACTUAL OR ANTICIPATED OUTCOMES

As indicated by the student survey results, the perceived utility and application of the in-class presentations and surrounding workshop discussions improved with the second implementation. Overall student engagement and enjoyment of the class guest lecture and tipi build workshop increased in 2024. The two-day tipi-build activities coupled with class and lab discussions improved the students' understanding of *both* Indigenous perspectives and fluid mechanics.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Given improved results and positive student responses from Spring 2023 and Spring 2024 tipi pedagogy workshop activities, the co-authors will aim to implement across other chemical and biological engineering coursework while honouring ancient, place-based knowledge systems. Furthermore, the authors intend to expand this effort locally and hope to inspire efforts globally.

KEYWORDS

Indigenizing Engineering Education

Introduction

Indian Education For All (IEFA) Essential Understandings: An Educational Mandate

Indigenous peoples have been engineering sustainable dwellings within resilient communities long before the arrival of colonial settlers. The design and build of these dwellings have been developed over countless generations by multiple tribal groups, incorporating important design elements to control heating and ventilation. These ancient design elements can be studied and understood as brilliant engineering solutions within sustainable, place-based knowledge systems – balancing local environmental factors and constraints such as climate patterns, seasonal food system patterns, and local resource availability. As a local example, there is much to learn and share from the stories and structures of the nomadic Plains tribes' traditional homes. The tipi (as illustrated in Figure 1) provides not only an intriguing overlap between Indigenous Knowledge and Western Sciences but also provides a pedagogical framework to provide culturally relevant educational experiences. This study aims to add to international academic efforts to *Indigenize and/or Decolonize Engineering Education* (Cicek et al. 2022; Cicek et al. 2023; Wolf et al. 2022).

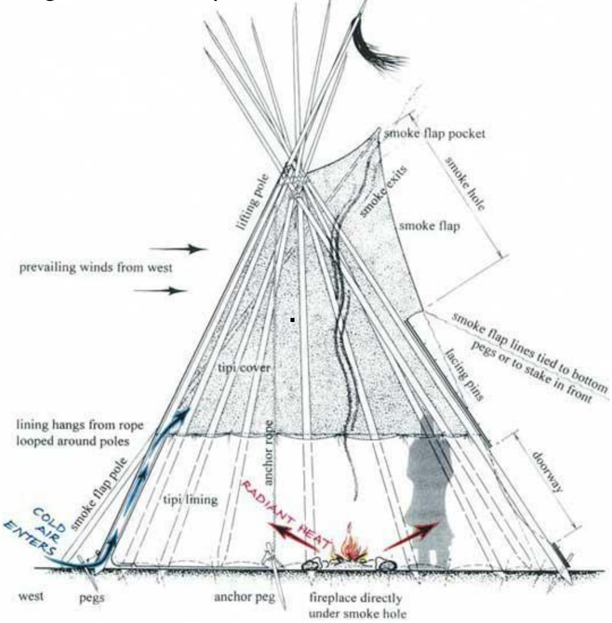


Figure 1: Cross-sectional (side-view) of a tipi with flows in, around, and out of the structure indicated with arrows. Key features are labeled with a person's silhouette for scale (Goble, 2006).

Global attempts to integrate Indigenous perspectives in engineering align with one of five broad drivers for decolonization: *educational mandates*, *policy mandates*, *industry mandates*, *social justice*, and *sustainability* (Cicek et al. 2023) with many examples across Australia, New Zealand, and Canada. As Cicek et al. observe in the relevant literature, "[Student] motivation, retention, and relevance are also key educational drivers… broadening the appeal of engineering education to minoritized and Indigenous students. This is a feature prevalent in the engineering/STEM outreach literature and particularly prevalent in Australia and New Zealand" (Cicek et al. p.71, 2023). In the United States, however, there is less evidence of these grassroots and larger organizational efforts to decolonize curriculum. This paper's authors' approach to developing these culturally responsive experiences in STEM at Montana State University (MSU) has been guided by a constitutional mandate in Montana that states "every Montanan, whether Indian or non-Indian, be encouraged to learn about the distinct and unique heritage of American Indians in a culturally responsive manner" (Montana Office of Public Instruction, 2024). The Essential Understandings, as compiled by representatives from various Montana Indian tribes, create a unique opportunity for dialogue and discussion in the classroom. In this instance, engineering and education faculty and students are building epistemological bridges between Western and Indigenous knowledge systems. In short, working within a "glonacal" context (Margin son &

Rhoades, 2002), as the authors move from the global to the local, *indigenizing engineering education* at Montana State University.

Relationships over Research: Spring 2023 Pilot Implementation Reflection

Building upon years of relationships between the co-authors and ensuing collaborative research efforts (Windchief et al. 2022), the co-authors piloted a guest lecture and tipi-building activity in a single (75 min) ECHM321 Fluid Mechanics course lecture period in the Spring of 2023. Fluid flow in and around objects is a foundational topic in various engineering disciplines, and this guest lecture sought to introduce Indigenous perspectives and IEFA Essential Understandings into the existing Chemical & Biological Engineering curriculum (Anderson et al., 2023). In the initial pilot implementation, the ECHM321 students were split into two groups: 1) classroom discussions led by the course instructor and an Indigenous graduate student, and 2) an outdoor hands-on tipi-building activity, led by one Indigenous co-author and an undergraduate research assistant. The indoor lecture highlighted presentation slides featuring images from recent computational fluid dynamics modeling efforts. Resources for the outdoor tipi-build included a 16-foot, Assiniboine-style canvas lodge cover, twenty-three lodge poles, ropes, stakes, lace pins, and canvas liners. An informal post-participant classroom survey collected responses to five numbered questions followed by a free-form response from students – which was distributed via email within a week following the workshop by the course instructor. The data is summarized in Table 1, with a couple of student responses also included below:

Table 1. Spring 2023 ECHM321 Student Survey Responses

Survey Questions (n=26)	Agree or Strongly Agree (%)
Q1: Overall, I enjoyed the class focused on the tipi and Indigenous ways of knowing.	**92.3 %**
Q2: I found the in-class presentation and discussion useful in my understanding of Indigenous ways of knowing.	**61.5%**
Q3: I found the tipi build to be useful to my understanding of Indigenous ways of knowing.	**76.9%**
Q4: I found the tipi build useful in my understanding of fluid mechanics.	**26.9%**
Q5: I now have a better understanding of how broader perspectives can help me be a better engineer in my career.	**73.1%**
Q6: Please provide any additional comments you have about the experience (e.g. parts you liked, things to improve, if/how it impacted you):	

> *I loved this experience and hope that this continues for fluids students in the future. It reassured me that what I want to do what my major has an impact and that I can apply different perspectives to engineering to help people… It was a very neat opportunity to get to connect a lot of the concepts that we were learning in class to a real world application. Very informational and interactive, all around a very positive experience.*

While a majority of students enjoyed the overall experience in the first year, the direct ties to the course material were less clear to many of the participants, as evidenced by Q4 responses' lower agreement rates. Motivated to address this apparent gap, the authors redesigned and expanded the educational experience across two different days of instruction so as to further integrate and emphasize the engineering principles in relevant aspects of theory/research, teaching, and application (Davis et al., 2024). Additionally, 2023 respondents noted the disadvantaged timing of having the guest lecture scheduled just before the second exam, so the lead course instructor adjusted the syllabus and schedule in the Spring of 2024, accordingly. In reflecting further upon the initial implementation study, the authors can align with the literature in which *Indigenous Knowledge in Engineering and Technology* can be conceptualized more specifically within local *place-based knowledges* (Page-Reeves et al, 2019). Although tipi structures can vary tribe by tribe within the northern Great Plains biocultural region, a pedagogical framework is emerging in which the tipi (think: academy) is grounded and supported by three-base poles (think: pillars) – which can be conceptualized as epistemology, ontology, and axiology and/or research, teaching, and service. Finally, in providing broader context and motivation beyond merely a case study of an ancient “real-world” application, these *decolonization* efforts can be conceptualized as/for *sustainability* consistent with our Australasian peers (Cicek et al 2023).

Methods and Methodologies

Indigenous Methodologies and High-Impact Practices

In stark contrast to the ‘traditional’ methods and methodologies in engineering instruction – i.e. standard course lecture with example problems led by a single expert (faculty) at the front of the room – this effort sought to engage students in a different mode of experiential and relational learning facilitated by multiple perspectives, which allowed for dynamic interactions between faculty-faculty, faculty-student, and student-student. Instead of simply reducing the tipi to an object to be studied strictly through a reductionist empirical engineering approach, students were first introduced and then invited into a mutually constructed space – building, investigating, and observing the tipi from multiple lenses and perspectives primarily through lived experience instead of merely relying on abstract reasoning to explore new course material. More traditional (indigenous) approaches, methods/methodologies, and projects are firmly grounded in relational worldviews deployed across various global contexts (Kovach, 2021; Smith, 2021; Wilson, 2008). In introducing the guest lecture presentation and tipi build workshop, *relationships* were therefore emphasized as a pre-requisite to this work and any successful research endeavor that is often overlooked when engaging Indigenous peoples and/or subjects. Indigenous facilitators led both the classroom lecture, and the tipi-building activity supported by recent engineering research efforts to collect experimental data on the airflow in, through, out, and around tipis and visualize fluid flow patterns on a laboratory scale (Davis et al., 2024). These relational, experiential approaches to research, teaching, and service align with high-impact educational practices (HIPs) – esp. *collaborative learning* in which students learn to work and solve problems in the company of others and benefit when listening to the insights of others with different backgrounds (Kuh, 2008). While HIPs have been shown to promote student achievement, diverse perspectives in engineering curricula have not been prioritized at MSU, despite being beneficial to broadening access and promoting the success of underserved students in STEM (Peters et al. 2019).

Methods

To address the primary aim of the study – i.e. utilize the tipi build and surrounding class exercises and workshop activities to improve the students’ understanding of fluid mechanics (Q4) – the workshop was redesigned as summarized in Table 2, below. Following the workshop, the exact same Qualtrics survey with identical questions as the one deployed in the Spring of 2023 was used to evaluate the efficacy of the intentional quality improvement efforts in course content and delivery in Spring 2024 – i.e. five Likert scale questions followed by a free-form response (Table 1, above). As a new and promising tool for both expediency and efficiency, Generative Artificial Intelligence (ChatGPT-4o) was utilized to compare, contrast, and help analyze and summarize the results of the survey response data. With a series of prompts, it was also able to generate the side-by-side comparative data visualization bar charts and in the figures, below. The generated comparative quantitative and qualitative data from this particular large language model were checked for accuracy by the authors and aligned with the authors’ experience and expectations.

Table 2: Tipi Lectures and Workshop Overview

Day (Group)	Format/Setting (Time)	Lead Facilitator
1(A) Background, Introduction	Classroom Lecture (35min)	Indigenous (Graduate) Student
1(B) Indigenous Methodologies	Outdoor Tipi Build (35min)	Indigenous Education Instructor
2(A) Tipi Fluid Calculations	Classroom Discussion (20min)	Engineering Course Instructor
2(B) Tipi Flow Measurements	Data Collection (20min)	Indigenous Education Instructor
2(C) Tipi Flow Patterns	Lab demonstrations (20min)	Research Asst (Undergraduate)

On the first day, the students (n~30) were divided into two separate learning groups (1A/1B), in Table 2) that would split equal time between the classroom lecture (~35min) and the outdoor tipi building activity (~35min) both led by guest Indigenous. On the second day, the classroom was split into three separate groups (2A/2B/2C) that rotated through three interactive stations ~20min each). In each of the rotating groups students were not passive participants but active learners. Student inquiry and engagement facilitated collaborative learning, in which the students' curiosity and questions drove interactive, dynamic discussions. Presentation slides were used to highlight recent research efforts to visualize, measure, and model tipi fluid mechanics using three distinct approaches: full-scale observations and measurements, analytical engineering calculations and computational fluid dynamics (CFD) modeling, and new fluid visualization techniques within a laboratory-scale tipi model – all illustrated in Figure 2, below.

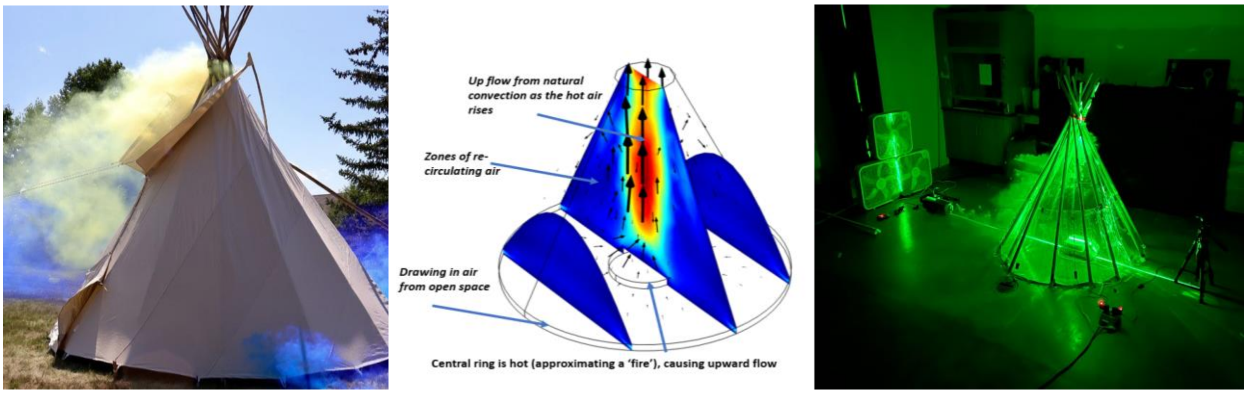


Figure 2: Tipi fluid visualizations: full-scale (left), software (middle), and lab-scale (right)

Resources required for the outdoor tipi build included a traditional 18' Sioux-style tipi canvas cover, twenty-three lodge poles, ropes, wooden stakes, pins/buttons, liner, and doors. During the rotating workshops on the second day, anemometers (Kestrel 5500 Weather Meters) were given to the students to measure actual conditions (wind speed, direction, etc.) outdoors and in the laboratory setting. The indoor laboratory set-up pictured above utilized a 6' (1/3 scaled) tipi with a transparent cover, where fog-machine generated "smoke" is illuminated by laser sheet light, fans model windy conditions, and a hot plate is utilized to drive natural convection. Within the classroom setting, course concepts, and learning objectives were explicitly and practically reinforced with students performing relevant (e.g. Reynolds numbers, annular flow acceleration, etc.) analytical engineering calculations. In short, the expanded second-day workshop activities were specifically designed to address the primary aim and objective of the study, which was made possible when one of the co-authors became the lead course instructor in Spring 2024.

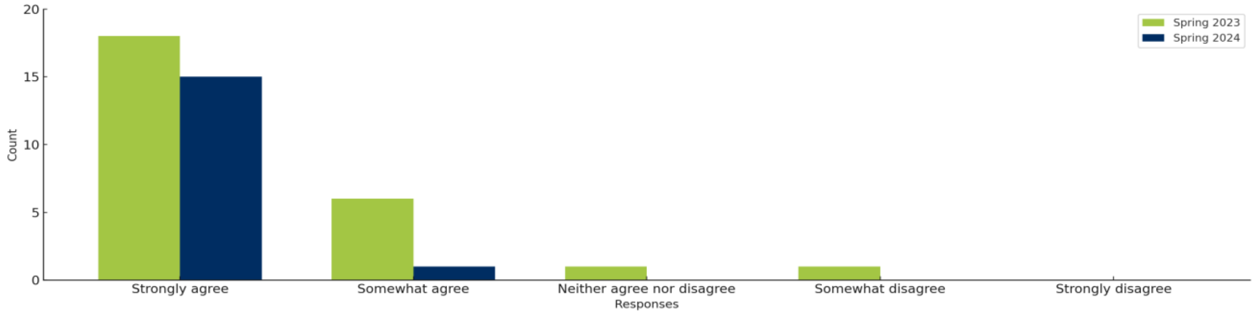
Limitations of the Study

For the purposes of transparency as well as highlighting opportunities for future research, this study focused on a specific group of engineering students (i.e. in one course in one institution) that limits the generalizability to other populations in different educational engineering contexts. The unique features of this study's context include an alternative curriculum (featuring Indigenous perspectives and essential understandings), and a relational pedagogy that might limit the applicability of the results in different settings serving to exclude some common engineering courses. Moreover, due to time/work constraints, the study applied convenience sampling with the student survey across two semesters, introducing potential bias and limiting qualitative analysis. Technological and measurement constraints include the use of a tipi as well as the inclusion of team members who are tribal members, who know how to set a tipi up, further limiting scalability or replicability. Not all institutions have access to a tipi or the relational knowledge to appropriately set one up. One of the researchers was also the instructor of the course under study, introducing potential bias. Finally, this study focused on local place-based (Indigenous) pedagogical interventions and/or contexts, which may limit generalization.

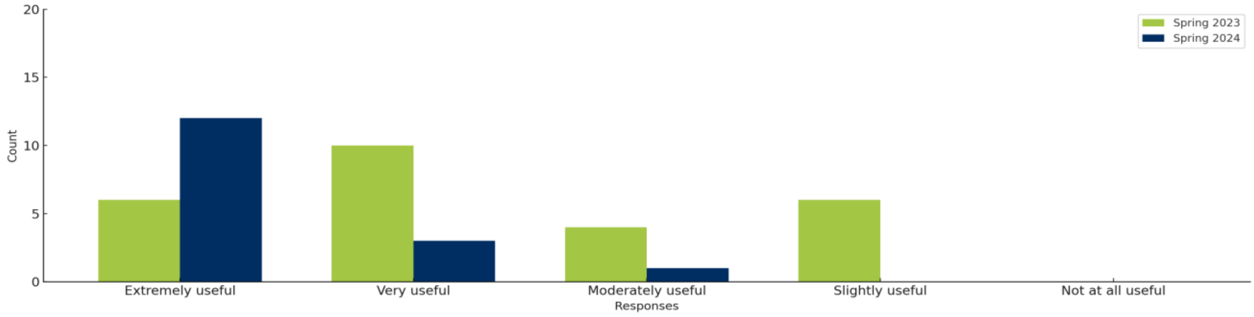
Results & Discussion

A Comparative (2023 v. 2024) Analysis

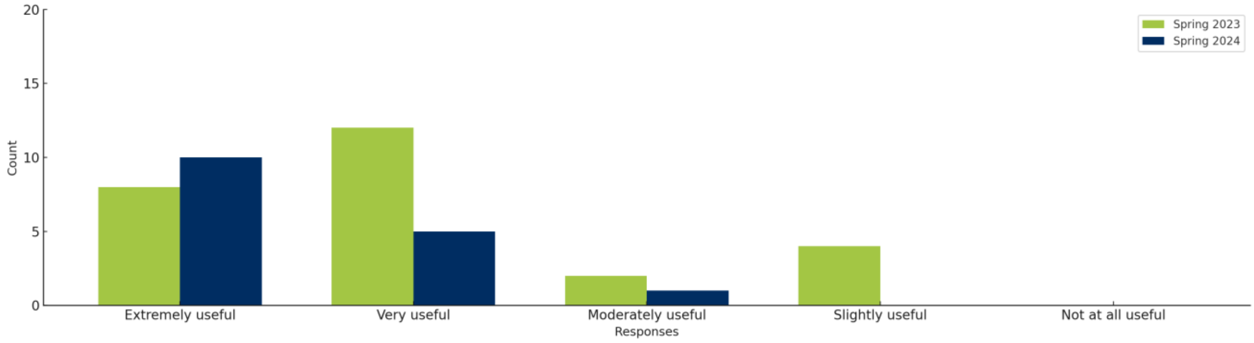
A link to the electronic survey was distributed by the course instructor via email to all of the course participants. Students were asked to complete the survey within the week following the workshop activity with fewer participants responding in 2024 (n=16 vs. n=26). Nevertheless, the overall engagement and enjoyment with the two-day guest lecture and rotating workshops with a majority of students indicating "Strongly agree" and a single "somewhat agree" to the first survey question (Q1). The perceived utility (usefulness) of both the in-class presentation (Q2) and tipi-build (Q3) increased the students' understanding of Indigenous ways of knowing, with most students finding the re-designed workshop "Extremely useful" or "Very useful" with no students indicating the opposite. A side-by-side (2023 v. 2024) comparison of student responses to the first three survey questions is shown in the bar charts in Figure 3, below:



Q1: "Overall, I enjoyed the class focused on the tipi and Indigenous ways of knowing."



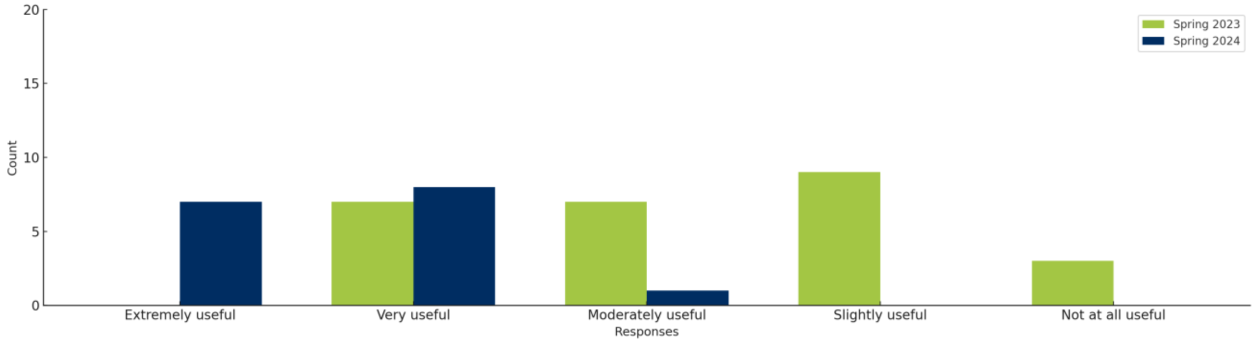
Q2: "I found the in-class presentation useful in my understanding of Indigenous ways of knowing."



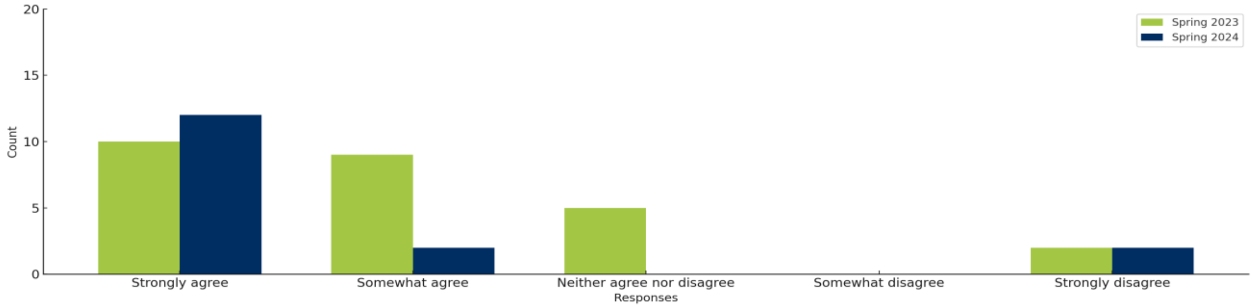
Q3: Q3 "I found the tipi build to be useful to my understanding of Indigenous ways of knowing."

Figure 3: Comparative bar charts of student responses to survey questions Q1 (top), Q2 (middle), Q3 (bottom) showing number of Spring 2023 responses (green), and Spring 2024 responses (blue).

Overall, the outdoor tipi build & measurements activity, laboratory scale display, and classroom workshops complemented and reinforced course materials in an experiential, hands-on manner that the students appreciated. Critically, student responses to Q4 demonstrate the success in addressing the primary aim and objective of this second effort to integrate and reinforce course concepts, as visualized in Figure 4 below:



Q4: "I found the tipi build useful in my understanding of fluid mechanics."



Q5 "I have a better understanding of how broader perspectives can help me be a better engineer...."

Figure 4: Comparative bar charts of student responses to survey questions Q4 (top) & Q5 (bottom) that critically address the primary aim and objective of this specific study by the number of student responses in Spring 2023 (green), and the number of student responses in Spring 2024 (blue).

As shown in bottom half of the Figure above, one single student did not appreciate how broader perspectives can help them be better engineers in both Spring 2023 and Spring 2024; however, a majority of student respondents indicated very strong agreement to the same question in both Spring 2023 and Spring 2024 with the above free-form responses in the following section providing additional support and insight. There were no responses that provided reason as to those who did not.

Qualitative / Thematic Analysis Toward a Grounded Theory

Building upon the success of the tipi fluid mechanics guest lecture and tipi build in 2023, the Spring 2024 student responses indicate a clear shift towards the positive (left) responses in every chart above. Students' free-form responses to the final survey question (Q6) provide additional qualitative agreement with the response rates to the first three questions, with insight and suggestions for improvement. A selection of the free-from responses follows:

> *I loved this experience and hope that this continues for fluids students in the future. It reassured me that what I want to do what my major has an impact and that I can apply different perspectives to engineering to help people… Spring 2023*
>
> *It was a very neat opportunity to get to connect a lot of the concepts that we were learning in class to a real world application. Very informational and interactive, all around a very positive experience… Spring 2023*
>
> *The talk helped me understand the why and actually being able to set up the tipi helped all of the lessons stick in my brain! It was a really useful learning experience… Spring 2024*
>
> *I would've enjoyed more time outside at the tipi, but the stations were perfect! I think the tipi experiment could have been a theme throughout the entire semester, rather than two lectures at the end… Spring 2024*
>
> *I thought it was so cool. I really liked how we both got to see the mathematical "reasoning" behind the shape of the tipi, like in the lab, but also got to interact with Indigenous people and see the lived reasoning behind the shape. The lab stuff was so, so cool, but I think it was so much more enlightening and valuable to learn it from people who've interacted with it their entire lives. It was also super fun in both situations to be able to understand things from the fluids perspective… Spring 2024*

ChatGPT 4-o was later prompted to apply a qualitative **Thematic Analysis of Student Responses** to the student free-form response, "Please provide any additional comments you have about the experience (e.g. parts you liked, things to improve, if/how it impacted you)" which was then reviewed by the coauthors to ensure clarity, concision, and accuracy as follows:

> *Qualitative analysis of the responses highlights that students appreciated the integration of hands-on learning with both theoretical (mathematical and scientific) and Indigenous perspectives. They found the cultural and lived experiences shared by Indigenous people valuable, expressing a desire for more interactive and participatory components… Overall, the experience was well-received, with most students finding it enjoyable, impactful, and enlightening.*

By integrating both quantitative and qualitative approaches (toward a grounded theory), the authors are able to validate findings through triangulation, using different types of data. As a group concerned with fidelity to the course concepts, program learning objectives, and student learning outcomes, the authors gained deeper insights into complex issues in Indigenous engineering education by examining both the measurable outcomes and the underlying processes integrating Indigenous worldviews.

Conclusions & Next Steps

The improved ratings for the workshop as a whole underscore the importance of intentionally integrating diverse perspectives and real-world applications into the curriculum while simultaneously reinforcing, *not compromising,* the delivery of critical course concepts, program learning objectives, and student learning outcomes. This study also demonstrated an increase in student engagement and enjoyment – which suggests that the relational and experiential nature of the tipi significantly enhances the learning experience – this aligns with high-impact educational practices that emphasize active and collaborative learning. Presentations by

Indigenous speakers added valuable context and depth to the student's understanding of Indigenous perspectives and essential understandings. The co-authors aim to continue implementing tipi pedagogy via guest lectures and workshops in adjacent chemical and biological engineering coursework such as heat transfer, reactor kinetics & design, transport phenomena, and an introductory course for first-year chemical and biological engineering students. Furthermore, with continued collaboration and funding support, the authors will develop weeklong workshops for other educators (regionally -> nationally -> globally) to design culturally responsive Indigenous engineering curricula while honouring place-based knowledge systems and Indigenous designs specific to their local context and region.

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