Teaching First-year Students to See Infrastructure Issues as Equity Issues

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Abstract

The fundamental role of civil infrastructure in helping to ameliorate or further exacerbate social inequities has become increasingly clear in recent years. In order to make more equitable decisions in how we plan, design, operate, and manage our infrastructure, civil engineers need to better understand the fundamental and ubiquitous role of infrastructure in society. This paper describes three first-year courses that address equity and infrastructure in different ways. At Lafayette College, a small, private liberal arts college, a first-semester course is focused on urban infrastructure and equity as a subject for critical reading and writing. At Gonzaga University, a medium-size private university, a first-year seminar is designed as a multidisciplinary exploration of infrastructure and equity. One of the primary learning outcomes of the course is to differentiate the ways in which knowledge is constructed across multiple disciplines, so infrastructure's impact on society is viewed through the lens of sociology, history, public health, economics, and engineering. At the University of Colorado Boulder, a large research-intensive university, a 1-credit civil engineering seminar course touches on the topic of infrastructure equity through the lenses of engineering ethics and sustainability. In all three courses, students created concept maps for "equitable infrastructure" at the end of the semester. The concept maps revealed differences in student ideas that reflect the different approaches taken in the courses. Analysis of these concept maps yields insight into student learning on equitable infrastructure and can provide guidance for others wishing to incorporate equity into first-year and/or civil engineering coursework.

Introduction

Civil engineering education has long recognized the need for the curriculum to blend a broad array of technical and professional skills to meet the needs of the profession (see, for example, the Civil Engineering Body of Knowledge [1]). The ways in which infrastructure has both positively and negatively affected equity in our social systems have become increasingly clear, leading civil engineering undergraduate programs to begin to include topics of equity into their coursework. In this paper, we compare three different models of teaching first-year students about equitable infrastructure. Evidence of students' understanding of equitable infrastructure was measured using concept maps. The paper provides insight into how faculty members at three

institutions addressed the topic in their courses and suggestions for others who may be revising their courses to add or enhance outcomes related to equitable infrastructure.

Background

Equitable infrastructure is defined as infrastructure that does not differentially impact disadvantaged communities, which historically have included a predominance of low-income people and/or persons of color [2]. Considering equity as an integral dimension of infrastructure is becoming more common, particularly in transportation [3, 4] and water [5]. The current ASCE Code of Ethics [6] implies that civil engineers should strive for equitable infrastructure. For example, under the society stakeholder, civil engineers should "acknowledge the community's diverse historical, social, and cultural needs and incorporate these considerations in their work." The idea of equitable infrastructure also aligns with the new ABET civil engineering program criteria (CEPC). Specifically, in November 2023 the Engineering Accreditation Commission (EAC) of ABET approved new civil engineering criteria that state: "The curriculum must include: A) Application of… iii) principles of sustainability, risk, resilience, diversity, equity, and inclusion to civil engineering problems" [7].

Use of the term "equitable" in conjunction with civil engineering is not without controversy. A discussion forum "equality and equity in engineering" at the ASCE Collaborate website dating back to 2021 presents points in opposition and support of equity [8]. It should be noted that during the 2023 public comment period for the proposed ABET CEPC, there were a number of concerns with respect to the addition of diversity, equity, and inclusion (DEI). In response, the ASCE Program Criteria Task Committee (PCTC) clarified that DEI topics were "integral to current civil engineering practice. … Recognizing a community's diverse elements, considering the differing needs of those elements, and seeking design solutions to meet those needs equitably are all crucial to the success of public infrastructure. Failure to understand these responsibilities … can result in a failed civil engineering solution that underserves all or segments of a community." Further, "the application of DEI principles is neither "political" nor "liberal progressive ideology." It is a professional skill essential to civil engineering design for a diverse public" [9].

Given the new ABET CEPC and increasing social concern, undergraduate civil engineering programs are increasingly seeking ways to integrate DEI topics into their curricula. Examples of compliance provided in the ASCE Commentary document [10] include: "using ratings systems such as Greenroads, ENVISION, and/or LEED to introduce students to metrics related to societal well-being", and case studies of past CE projects that "failed to address the needs of an underserved community (e.g., the 2014 Flint, Michigan, water supply crisis)" [11, 12]. There are an increasing number of examples of efforts to introduce issues of equity in concert with infrastructure in the literature. Sanford et al. conducted a systematic review of literature

describing interventions that have been implemented in practice [13]. Examples include Casper et al.'s efforts to integrate social justice into first and third year civil engineering courses [14], case studies developed by Judge [15], and Castaneda et al.'s integration of engineering justice into a statics course [16].

In addition to responding to ABET and professional expectations and aspirations, courses that address issues of equity in infrastructure have the potential to attract more, and more diverse, students to the civil engineering profession. Civil engineering has been struggling to attract students, as compared to disciplines like mechanical engineering that have experienced large increases in enrollment over the past decade. For example, based on ASEE data, the number of Bachelor's degrees awarded in Civil plus Civil/Environmental Engineering increased by 977 between 2013 and 2022 as compared to an increase of 11,065 in Mechanical Engineering [17], [18]. Embracing equitable infrastructure as a fundamental concept in Civil Engineering education could help attract and retain students. Research has identified helping others and equity as motivating some students to pursue engineering [e.g.,19]. But some students also leave engineering when they perceive other majors as more supportive of those goals (e.g., [20], [21]). Thus, introducing students to equitable infrastructure in early civil engineering courses might inspire students to choose and persist in careers in civil engineering.

Further, research into career choices has shown a perception by students that STEM fields are in opposition to the goal of helping others, and this has been identified as a possible contributing factor to underrepresentation of women in these fields [22]. Linking the engineering profession to societal challenges has been viewed as a way of counteracting these perceptions to address underrepresentation of women in engineering and also to produce more ethical and socially aware engineers as a whole. Previous research that looked longitudinally at engineering students' views of public welfare concerns showed these views declining over the course of the students' engineering studies [23]. Another study highlighted the importance of ethical and societal impact content in undergraduate engineering education as being key to developing students' awareness that these impacts are part of the responsibility of engineers [24]. The cumulative picture of this research illustrates the importance and complexity of inclusion of equity and social context in engineering programs for both career selection and student professional development.

Course Descriptions

The three courses that are the focus of this study were taught by the authors at three different institutions in the Fall 2023 semester. The paragraphs below explain the context for each course. Key readings, podcasts, and videos related to equitable infrastructure that were included in the course are listed in the Appendix.

Lafayette College, a small, private, liberal arts college, requires all students to complete a first year seminar course (FYS). The primary purpose of the FYS is to introduce students to college-level reading, writing, and thinking skills with a common set of learning outcomes. Each FYS instructor develops their courses with a theme that related to their areas of interest; the instructor may add additional learning outcomes related to the theme. Students prioritize their top choices of themes and typically are placed into one of their top three choices; sections are capped at no more than 16 students. The course discussed in this paper, entitled "Sustainable Cities: Urban Infrastructure and Equity," enrolled 13 students, five of whom expressed an intention to pursue one of the available engineering majors. Unusually, all 13 students were male. The 1-credit course met for two 75-minute class sessions per week and also for lunchtime guest speakers and other out-of-class activities (all 1-credit courses at Lafayette College are equivalent to 4-credit courses under typical semester credit hour counting). Students completed substantial reading and writing assignments both inside and outside of class, and classes were largely discussion based.

The topic-specific learning outcomes for this course are that students should be able to 1) explain how infrastructure affects their own lives and the lives of others in their home community on a daily basis and 2) analyze the differential equity and justice impacts of infrastructure on a community with regard to health, employment, wealth, etc. Writing assignments included a reflection on "What is a city?," an infrastructure biography (in which students reflected on how a particular type of infrastructure has affected their lives), an infrastructure walk (in which students wrote about their observations and reflections on a 1-mile walk in our local community), and an investigation and reflection on impacts of redlining on infrastructure today in a selected city. Students began and ended the course with a concept map exercise using the instructions in Figure 1.

Your task is to develop a concept map for "Equitable Infrastructure" (i.e., a map that in visual terms answers the question, "What is equitable infrastructure?")

- Brainstorm for a few minutes and, on this or another sheet of paper, write down terms and short phrases that are connected to your current understanding of equitable infrastructure.
- On a *new* sheet of paper, draw a concept map based on your brainstorming, placing "Equitable Infrastructure" at the center or top of the drawing and drawing lines to other related concepts.
- After you have sketched in the primary associations, move on to add secondary or tertiary levels of association (or more), if appropriate.
- Determine the ways in which the various concepts are related to each other and write those types of relations on the lines connecting the concepts.

Figure 1. Student prompt for concept map exercise

Gonzaga University, a medium-sized, private liberal arts university, requires all first-semester students to complete a first-year seminar course (FYS). Each FYS has the following common learning outcomes 1) differentiate the ways in which knowledge is created, 2) articulate how their own perspectives affect their discovery and generation of knowledge, and 3) integrate principles of Gonzaga's Mission with their academic, personal, and spiritual aspirations. The theme of an FYS course is left up to the individual instructors and the course discussed in this paper was entitled "Equity and Infrastructure." Although the course fulfills the university core requirements for an FYS for any major, students enrolled in the course were primarily engineering majors; out of 21 enrolled students only two were not engineering majors. Students are enrolled in an FYS based on either expressing an interest in that particular course during an orientation survey or by major if no specific FYS was indicated.

In addition to the aforementioned FYS learning objectives, this course also had an optional social justice core designation with additional learning outcomes of 1) describe how social systems affect people, 2) understand and articulate how are attitudes and behaviors shaped by biases, 3) articulate the ethics behind working toward common good, and 4) demonstrate commitment to the need for working toward a more just world. FYS courses also can carry learning outcomes related to the course theme, and this course had the objective of students being able to discuss the connections between the practice of civil engineering and the impacts of civil engineering infrastructure on society.

The 3-credit course met twice a week in a seminar style and focused on active learning activities, field trips, guest speakers, and small group discussions. Substantial readings and reflective writing assignments outside of class were required. Students ended the course with the same concept map exercise as the other institutions that were part of this study (Figure 1). The course used interstate highways as a case study to explore how infrastructure impacts society from both historical and modern perspectives. Students were tasked with developing their own case studies in other areas of infrastructure and presented these to the class during the final weeks of the semester. The course also looked at the future of infrastructure in terms of climate resiliency and emerging technologies using ASCE's Future World Vision platform.

At the University of Colorado Boulder, a large public institution, students were introduced to ideas related to equitable infrastructure (EI) in a first-year Introduction to Civil Engineering course. The course was 1-credit and met once per week for 50-minutes over the 15 weeks of the semester. In most weeks, students completed a reading and/or watched a video and then submitted a 250-500 word response to structured prompts. There were 53 students enrolled in the course, including 38 students majoring in civil engineering who were required to take the course. Other students were engineering majors who had not yet selected their specific major in engineering, but had some interest in CE as they selected it as an elective.

The primary learning objectives in the course related to helping students understand the civil engineering profession and expand their understanding and interest in CE as a major. The course did not include a learning objective specific to EI but did include related topics of civil engineering ethics, sustainable engineering, and diversity, equity, and inclusion (DEI) [25]. These specific learning objectives were:

- Describe the ethical behavior expected of civil engineers
    - Discuss how at least two sub-parts of the ASCE Code of Ethics relate to the interstate highway and local community in Tampa Florida
- Define sustainable engineering and describe its importance to civil engineering
    - Describe how credits in Envision relate to the situation in Isle de Jean Charles
- Discuss why equity, diversity, and inclusion issues are of concern in civil engineering, and how these issues might affect you personally in your future career and work

In the ethics module in Week 4, students heard the story of a Black community member from Tampa, Florida describing the disruptions of the interstate highway to her community. The sustainability module in Week 6 introduced the Envision sustainability rating system, which students applied to the relocation of the Native American community of Isle de Jean Charles due to sea level rise and land loss. Within the DEI module in Week 7, students were introduced to the definition of equity, and they chose two readings or podcasts from a selection of resources; some focused on DEI issues in the workplace while others explored historical examples of inequity. The course also embedded ASCE's Future World Vision platform and topics like design, data science, creativity, and careers in CE. The term equitable infrastructure was not directly used in the course prior to the shared concept map evaluation activity in Week 14.

Methods

The research was deemed exempt by the Lafayette College Institutional Review Board (AY 2024-36).

For this study, the authors used concept maps at the end of the semester in three different first-year courses to explore students' understanding of equitable infrastructure. Concept maps are visual representations of the attributes that relate to a selected idea, and they also illustrate how these sub-ideas relate to each other. They can be used as a learning tool to help students explore new ideas, going from higher level ideas to more detailed specifics, and they also can be used to assess students' understanding of complex ideas (e.g., [26], [27]). Concept maps have been used as educational tools in civil engineering (e.g., [28], [29]), including with first-year students (e.g., [30], [31], [32]) and related to sustainability (e.g. [33], [34], [35], [36]). Research has found that more simplistic knowledge tends to result in spoke structures, while greater expertise tends to result in network and web formats that include more concepts and greater

numbers of connections among the ideas [37]. Concept maps also can reveal attributes that are common and missing from students' knowledge.

Concept maps were chosen as a method for this study for several reasons. First, as noted above, the three courses are quite different in terms of format and content, although there are overlapping learning outcomes related to equitable infrastructure. Thus, the concept map format, in which students "write what they know," allowed us to look across these disparate courses for common understanding. Second, and relatedly, the concept mapping exercise is an authentic learning activity rather than an activity that solely provides information for research purposes; we are "eavesdropping" on student learning and using it for research purposes (with their permission, of course). In this way, it is similar to an embedded indicator for assessment purposes. Finally, the concept mapping activity is both low-stakes and not particularly time-consuming. In all three courses it was a short, graded activity; it required approximately 20 minutes of class time and grading was on completion rather than correctness,

The same concept map activity was conducted in all three courses during an in-person class meeting near the end of the semester (Figure 1). Students were given a hard copy of a 1-page consent form. All students completed the activity regardless of whether they consented for their work to be included in this research study. At Gonzaga and the University of Colorado Boulder, students were introduced to the idea of concept maps for the first time in conjunction with the activity (first formal instruction), while students at Lafayette College had completed a similar concept map assignment early in the semester. Additional relevant details of implementation at each institution include:

- At Lafayette College, this concept map activity was introduced during the final class meeting of the semester. The instructor reminded students of the concept-mapping exercise they completed on the first day of the semester and explained that once they completed this assignment, they would be given their original maps to review and asked to compare and reflect on similarities and differences between the two. All twelve students present consented to participate in the research study, and most students spent about 20 minutes developing their concept maps.
- Students at Gonzaga University completed the activity during the final exam period. Students knew there would be a culminating in-class assignment but were not told any details about the activity in advance. Three students did not attend the class and all students in attendance consented to be included in the research study. This activity was the first time in the course that students were asked to construct a concept map, and students were given about 20 minutes about midway through the class to complete the activity.
- At the University of Colorado Boulder, students were introduced to the concept map activity as an in-class exercise during the last 20 minutes of class in Week 14. This included about 5 minutes to explain concept maps and discuss the informed consent

process. Students were told that their name on their map would be used to log attendance points. If they opted to participate in the research, they additionally submitted the completed consent form. Only 29 of the 53 students enrolled attended the class session when this exercise was completed; 21 of these consented to participate in the research. Most students spent about 10 minutes on their concept maps.

Response rates for students who consented to participate in the research out of the total number of students enrolled in these courses were: Lafayette College 92%, Gonzaga University 86%, and the University of Colorado Boulder 40%.

Concept maps were evaluated both by a traditional quantitative scoring method [38] and by coding qualitative concepts. An example student concept map is shown in Figure 2. For the scoring, the number of nodes (concepts) and the number of links on each map were counted. If a link included an arrow head on both ends (indicating two-way interactions), this was counted as two links. The number of cross-links (CL) was calculated as the number of links minus the number of nodes. The highest hierarchy (HH) on each map also was counted, representing the "depth" of a single chain of ideas on the map. Finally, a total score was calculated (nodes + 5 HH + 10 CL). In addition, the total number of words that were part of each map was tallied. This included words in the concepts (some students used one-word concepts in each node whereas others had a more extensive description) and words on the links. Differences among these quantitative metrics for the concept maps across the institutions were compared statistically using 2-tailed t-tests.

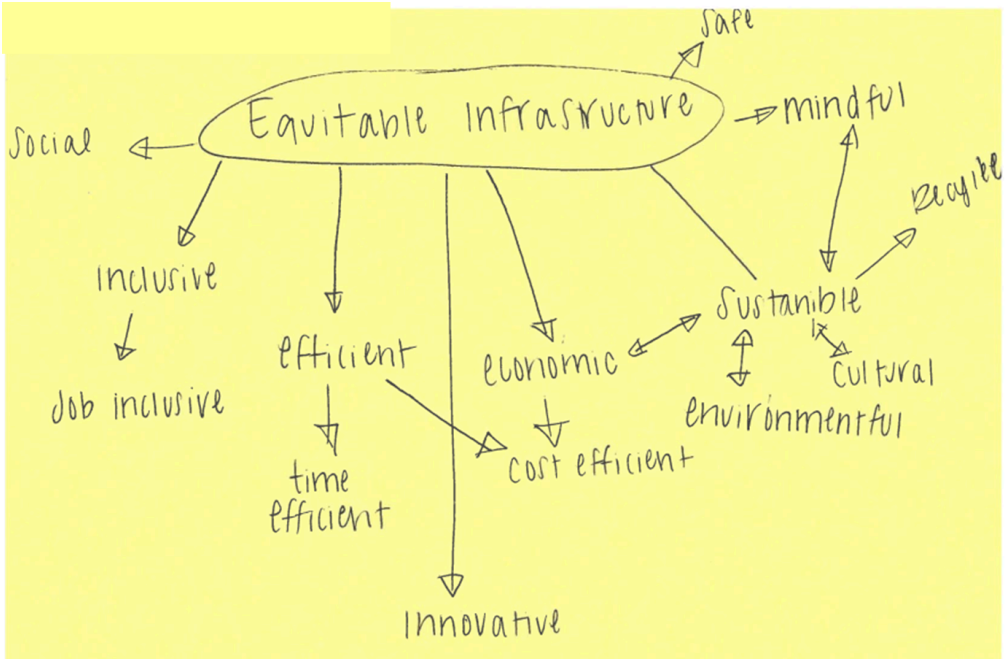

Figure 2. Concept map from the University of Colorado Boulder with 14 nodes, 7 cross links, and highest hierarchy 4; holistically classified as sustainability focused.

Emergent coding methods were used to identify common concepts that were present in the maps. Review of the concept maps initially identified 20 themes, which were coded a "1" if any of the associated terms with each theme were used in the map at least once. If none of the associated terms were used, the theme was coded a "0" for that concept map.

In addition to identifying specific themes, the authors characterized holistically the overall balance of ideas included in each map. The general categorizations that were used were: maps predominated by equity / social ideas, maps predominated by infrastructure concepts, maps balanced among equity and infrastructure, maps focused on sustainability concepts, and a few others that did not fit these common patterns.

Results

Quantitative Metrics

Table 1 summarizes the counts for concepts, highest hierarchy, and cross links. Maps created by students at Lafayette College had more nodes, cross links, and words, and higher overall scores than those at the other institutions. These students had previously constructed concept maps, and this greater familiarity might have contributed to the more extensive maps created by the Lafayette students.

Table 1. Average, standard deviation, and range of quantitative Equitable Infrastructure concept map metrics

School	Nodes	Cross Links	Highest Hierarchy	Overall score	Total words
L (n=12)	23±10 (10-40)[a]	8±9 (0-32)[a]	5±2 (2-10)[a]	129±36 (21-377)[a]	59±30 (21-116)[a]
G (n=18)	16±6 (8-31)[a]	2±3 (0-7)[b]	5±2 (3-9)[a]	62±29 (24-10)[b]	36±24 (11-117)[b]
C (n=21)	11±5 (3-20)[b]	5±5 (0-19)[a]	4±1 (2-7)[b]	78±52 (23-217)[a,b]	36±24 (12-111)[b]

Conditions with the same superscripts are not significantly different (e.g., a and a) while different superscripts (a vs b) represent $p < 0.05$ in a 2-tailed t-test. For example, the number of nodes from University of Colorado [C] (b) is different from the number of nodes from Lafayette College [L] and Gonzaga University [G] (a).

Thematic Coding

Table 2 shows the percentage of concept maps at the three institutions that contained each of the themes. Only themes for which at least 10% of the maps at one institution included that theme are represented in the table. The combined percentages are shown in the final column. Bold text

indicates overarching themes such as Sustainability and Infrastructure, and shaded cells in the table highlight themes contained by the majority (50% or greater) of the maps.

The Infrastructure and Cost/Economic themes were found in the majority of the concept maps at all three institutions. Although they were not in the majority of the maps at all three institutions, the Community/Cities/Citizens and Transportation themes also were identified in the majority of the maps when the institutions were combined. The considerable differences in most of the themes between institutionsare both expected and understandable because each institution followed its own curriculum with variations on the topic coverage and amount of emphasis. The appendix of this paper provides reading lists and resources used at the three institutions; these materials illustrate the differences in course design.

Holistic Characterization

A holistic review of the concept maps also was conducted by each of the authors to identify overall trends such as whether the concept maps focus primarily on an overarching concept like infrastructure, equity, or sustainability or if they were more balanced among these major areas. For example, a concept map was categorized as "infrastructure" if it contained a lot of depth about different types of infrastructure or infrastructure-related subtopics (see Table 2) but had little to no depth in equity topics. A balanced concept map had more equal coverage of infrastructure and equity topics. Table 3 summarizes the results for this holistic analysis.

Figures 3 and 4 show examples of maps characterized as equity-focused and balanced, respectively. In Figure 3 from Lafayette College, the student created several branches related to equity topics, including infrastructure to serve people of all abilities and redlining/discrimination. The other main branches related to Sustainability and Funding. For Lafayette College, six of the maps were balanced, including concepts related to both equity and infrastructure, four focused largely on equity, and two focused primarily on infrastructure concepts.

The concept maps for Gonzaga University were mostly categorized as balanced, with 15 of the maps (83%) labeled this way. Figure 4 shows an example of one of the concept maps classified as balanced, with major branches in equity concepts including redlining, Justice40, and minority population as well as infrastructure concepts including highways and construction. One of the interesting differences found in the concept maps at Gonzaga was the level of interconnectedness between the infrastructure and equity concepts within the map. The map in Figure 4 shows relatively little connectivity, although this was one of the few that provided link labels. The most common map theme at the University of Colorado Boulder was sustainability, and some of the concept maps didn't fit any of the common types, such as one with a design focus, one that repeated the idea of trade-offs, and a third that was very weak (only 3 nodes) and was not characterized. The University of Colorado Boulder maps reinforce that when the students were

Table 2. Percentage of the student concept maps at each institution that contained various themes

Theme	*Examples*	*L*	*G*	*C*	*All*
Sustainability	Sustainable, Sustainability	**25%**	**11%**	**38%**	**25%**
Environment	Environment, Greenhouse Gases,GHG, Emissions, Pollution, Environmental Impact Statements, Climate	42%	33%	43%	39%
Safety/Health	Safety, Health, Clean Water	50%	28%	33%	35%
Society/Social	Social, Society, People, Population, Human	58%	17%	33%	33%
Communities/ Cities	Cities, Citizens, Communities, Marginalized Communities	58%	56%	48%	53%
Cost/Economic	Cost, Economics, Economy, business/businesses, Funding, Money, Taxes, Pricing	75%	56%	67%	65%
Ethics	Ethics, Ethical	8%	0%	19%	10%
Diversity	Diversity, DEI, Inclusion, Minority/Minorities, Low Income, Race, Classes, Poor/Rich, Demographics	**50%**	**50%**	**43%**	**47%**
Opportunity	Opportunity, Jobs	8%	28%	33%	25%
Social Justice	Social Justice, Equity, Inequity, Bias	33%	39%	10%	25%
Infrastructure	Infrastructure (any type)	**67%**	**89%**	**67%**	**75%**
Transportation	Transportation, Highways, Interstate, Buses, Public Transport Transit, Bridges, Trains	67%	89%	29%	59%
Water	Water, Pipes	42%	33%	10%	25%
Housing	Housing, Houses, Low Income Housing	67%	28%	10%	29%
Energy	Energy, Power, Electrical/Electricity	25%	17%	10%	16%
Other Themes					
Trade-offs	Trade-off(s), Pros/Cons, Benefits/Costs, Good/Bad	8%	0%	19%	10%
Policy/ Legislation	Policy, Laws, Legislation, Redlining, Justice40, Environmental Justice, HEAL Act, Government, Legal	58%	39%	5%	29%
Innovation	Innovation, Innovate, Future World Vision	8%	0%	19%	10%

not explicitly introduced to the term equitable infrastructure they infer a meaning, with most linking EI to the related idea of sustainability, which was emphasized in the course.

Table 3. Percentage of the student concept maps classified as each type

Map type	*Lafayette College*	*Gonzaga University*	*University of Colorado-Boulder*
Balanced	50%	83%	10%
Equity / social	33%	6%	19%
Infrastructure	17%	6%	14%
Sustainability	0%	0%	43%
Other	0%	6%	14%

Figure 3. Concept map from Lafayette College classified holistically as equity focused.

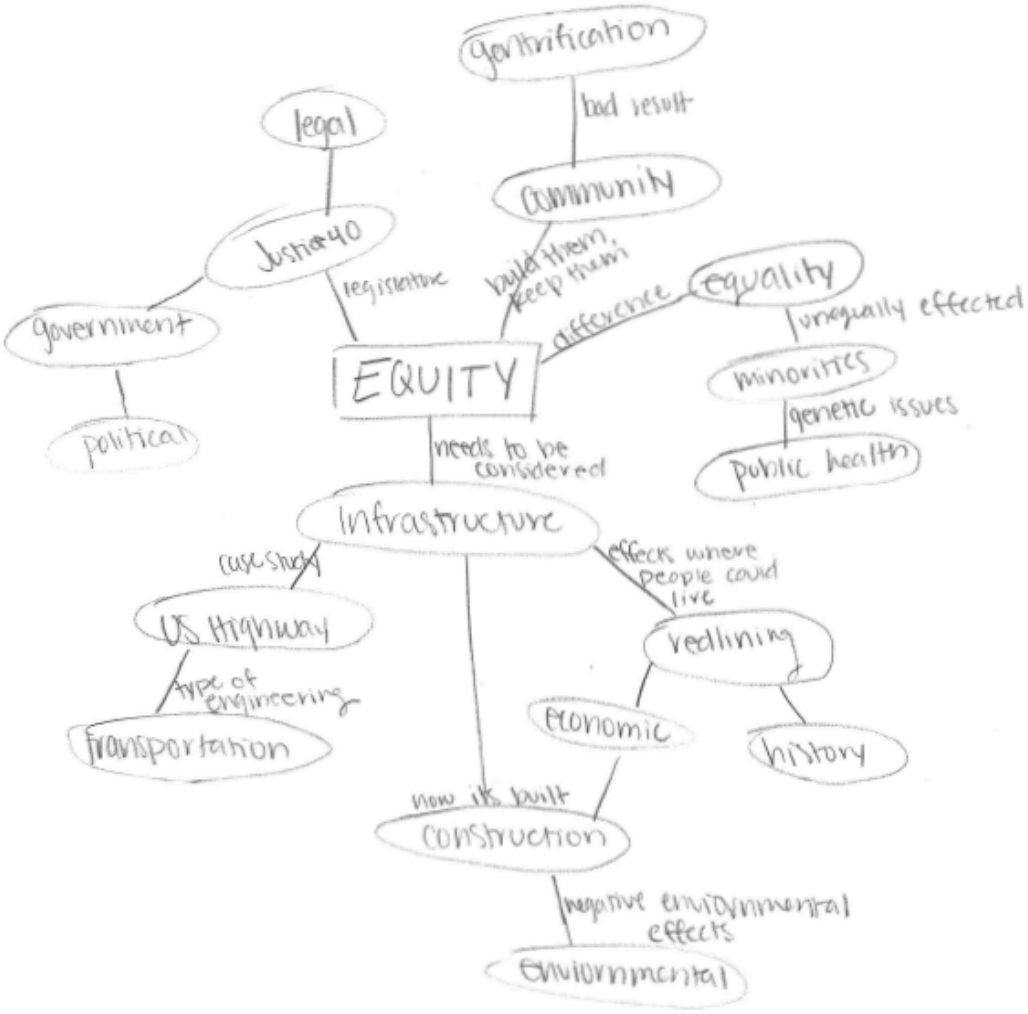

Figure 4. Concept map from Gonzaga University classified holistically as balanced but with limited connections between equity and infrastructure concepts.

Discussion

There are a variety of approaches to teaching first-year engineering students about equitable infrastructure. In this study, two of the institutions approached the subject directly in a class fully focused on equitable infrastructure. The third institution touched on the topic indirectly via the related ideas of ethics and sustainability. The next section discusses our reflections as instructors and what we learned from conducting the end-of-semester concept map exercises, and the following section provides suggestions for those who are considering integrating DEI issues into their teaching about infrastructure.

Reflections

At Lafayette College, concept maps commonly included the term “redlining”, as well as some specific types of transportation infrastructure. This reflects particular course activities in which students learned extensively about the history and impacts of redlining and explored how redlining has affected a city of their choosing. They also learned about the importance of walkability and transportation equity, concepts that were reflected in their concept maps, through planning and completing both a trip on a local transit system and an infrastructure walk. In the future, ensuring that students engage with a wider variety of infrastructure could help reinforce broader concepts of sustainability and environmental justice.

The balanced nature of concepts map at Gonzaga University reflected the balanced content in the course, which was intentional in the design of the course as a multi-disciplinary exploration of the relationship between equity and infrastructure. The differences in the level of integration of the concepts in many of the student maps highlighted the need for more explicitly discussing and highlighting the connections in future course offerings. Additionally, concept maps might be introduced in an earlier course activity to develop familiarity with the tool prior to this culminating activity since it was apparent during the mapping activity that prior exposure to concept maps was limited.

The sustainability and ethics themes that were common among the concept maps from students at the University of Colorado Boulder are aligned with the lenses used in the course. The course lectures and required references did not explicitly use the term “equitable infrastructure”, and thus students needed to tie multiple ideas together to construct their own understanding of this concept. In addition, only about 3 hours of class content were related to EI at University of Colorado Boulder compared to much deeper engagement with the topic in the courses at Lafayette College and Gonzaga University. Thus, the lower quality of student knowledge on equitable infrastructure at University of Colorado Boulder is congruent with the instructional focus.

Using the concept map as an in-class, ungraded activity at the end of the semester (as at the University of Colorado Boulder) may not motivate students to give their best effort and fully reflect their knowledge. Previous research at the University of Colorado Boulder found similar quantitative metrics (e.g., median number of concepts 11-12, total score 43 and 47.5) among in-class sustainability concept maps near the start of the semester [31]. In contrast, the concept maps generated as part of graded homework or final exams were more extensive (e.g., median 22-27 concepts, total score 75-95). Thus, the short in-class activities might reveal “top of mind” ideas for students but not be accurate indicators of deeper or more extensive understandings that take more time and effort to articulate.

Suggestions

This paper presents multiple ways that first-year students were introduced to the topic of equitable infrastructure. The four- and three-credit first-year seminar courses at Lafayette College and Gonzaga University were highly focused around equitable infrastructure and aimed for in-depth student learning about this complex sociotechnical issue (a first year seminar is required but the themes vary). The University of Colorado required course was a more traditional introduction to civil engineering as a whole, and only a single credit. The authors believe there is value in introducing students, and especially civil engineering students, to the challenge of equitable infrastructure early in their curriculum. However, curricula are constrained, and faculty may not feel qualified to teach an entire course on this complex topic. Equitable infrastructure could be integrated into more standard required courses such as an introduction to infrastructure (e.g., a required sophomore level course at the University of Wisconsin Platteville), sustainable civil engineering (e.g., a required sophomore course at Rose-Hulman Institute of Technology), civil engineering systems (e.g., Georgia Tech, University of Texas Austin), transportation engineering (sophomore / junior level course at many institutions), fundamentals of environmental engineering (sophomore / junior level course at many institutions), or professional issues (junior / senior level course at Lafayette, the University of Colorado, University of Texas Austin, University of Washington, and other institutions). Integrating the idea of equitable infrastructure in multiple courses is likely a best practice, similar to work that has demonstrated the efficacy of ethics and/or sustainability across the curriculum approaches [39].

A particularly effective integration strategy may be to use a case study approach. These case studies typically are not integrated into textbooks and will require the instructor to bring in external sources. Such case studies could be historical (e.g., Hurricane Katrina) or somewhat more contemporary (e.g., Flint Michigan). Characterizing these real world civil engineering problems as sociotechnical issues situates the technical concepts students are mastering in their sociopolitical context. Thus, discussion and debate around equitable infrastructure topics should be expected and encouraged. Learning assessment could include individual reflection, group reflection, and/or concept mapping.

The courses at Lafayette College and Gonzaga University both covered the construction of the interstate highway system beginning in the 1950 as an equity issue. This case study has both a strong historical lens as well as contemporary framing since the Federal Infrastructure Investment and Jobs Act has a funding program called Reconnecting Communities and Neighborhoods, which is targeting investment in areas that were negatively impacted by past projects like the interstate highway system. The Gonzaga University students were able to tour a new freeway under construction in Spokane; this new freeway connects to an existing interstate that divided a racially diverse neighborhood in the 1960's. The students learned how this neighborhood is being impacted by the new project and looked at efforts by the state to not only

minimize additional impacts but also how the transportation agencies are trying to leverage funds from the new freeway project and the Reconnecting Communities program to address historical harms experienced by the community.

Conclusions

This paper presents three different approaches for introducing first-year students to the idea of equitable infrastructure. Introducing engineering students to these ideas in their first year can have a variety of benefits. In particular, it communicates the important sociotechnical nature of engineering and the critical impacts that civil engineering can have in advancing or hindering equity in society. Rather than avoiding this complex topic, first-year students are perhaps uniquely open-minded to considering the challenges posed by striving for equitable infrastructure. The topic might particularly resonate with some groups and draw the interest of students as a contrast to traditional first-year courses in calculus and physics. In addition, there are opportunities to integrate equitable infrastructure ideas into later courses such as a mid-level transportation engineering course or professional issues course. The concept of equitable infrastructure ties to a number of the educational requirements in the updated ABET civil engineering program criteria (e.g., sustainability, ethics, DEI).

Concept mapping provided useful insights to the instructors about key ideas that students took away from the course. It is appropriate that the concept maps revealed differences in the topics and approaches from each course. Students in the courses at Lafayette College and Gonzaga University developed richer ideas about equitable infrastructure than did the students at the University of Colorado Boulder. The instructor at the University of Colorado Boulder learned that introducing students explicitly to the term equitable infrastructure is important for development of a multi-faceted understanding of the concept. We believe that concept mapping should not be viewed as solely a research tool but rather a valuable teaching and assessment activity for students.

The three approaches to the topic of equitable infrastructure described in this paper were distinct, and each course offers resources that faculty members at other institutions may find helpful. Opportunities exist for a small introduction to the topic of equitable infrastructure (e.g., the University of Colorado Boulder in alignment with sustainability or ethics) or a full three- or four credit course with deep engagement. There isn’t a single “right” way to teach students about equitable infrastructure. However, our experiences suggest that introducing students to this complex idea early in their civil engineering education can help frame the sociotechnical nature of the discipline.

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Appendix - Reading Lists

Resource List for Lafayette College

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7. *"Place Matters"* Poetry/Spoken Word by Clint Smith *https://www.youtube.com/watch?v=saREW_BfxwY*
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Mapping Resources:

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3. *Underserved Communities Census Tracts (Historically Disadvantaged Communities)* USDOT Map for Grant Funding https://usdot.maps.arcgis.com/apps/dashboards/99f9268777ff4218867ceedfabe58a3a

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3. ASCE Code of Ethics (2020)
4. ASEE Community Panel Video, Darshan Karwat, Lena Young Green, Chief Albert Naquin
5. ENVISION sustainability rating system for infrastructure
6. FWV MegaCity2070 (there are DEI elements embedded in the scenario; find some of these) https://www.futureworldvision.org/
7. National Society of Professional Engineers (NSPE) Why Should I care about diversity in Engineering? 2020 [resource option] https://www.nspe.org/resources/pe-magazine/july-2020/why-should-i-care-about-diversity-engineering

8. Engineering more equitable Communities, 12-min video, Autodesk https://www.autodesk.com/autodesk-university/content/Engineering-More-Equitable-Communities [resource option]
9. How Diverse Teams Drive Innovation, 22-min video, Migual Alemany interview by American Society of Civil Engineers: https://www.asce.org/publications-and-news/civil-engineering-source/article/2022/06/15/how-diverse-teams-drive-innovation-part-1 [resource option]
10. ASCE Examining social equity in infrastructure; ~25-min, Maya Trotz, https://www.youtube.com/watch?v=Vy1wHvPlGi0&list=PLA61bxD8Jg-2ZiW3R-EabzvFVNJda_KvH&index=6 [resource option]