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Assessing Student Learning in Collaborative First-Year Engineering Projects Through Mind Maps

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Abstract

This study investigates the use of mind maps as a tool to measure and support collaborative learning in first-year civil and architectural engineering projects. This research focuses on how mind maps can assess changes in students' knowledge, perspectives, and problem-solving approaches throughout a community-focused design project. The project engaged students in developing sustainable design solutions aligned with realistic constraints and stakeholder needs. Three mind maps were used to track learning progression: an initial individual mind map, a collaborative team mind map, and a final individual mind map.

Quantitative analysis showed a significant increase in mind map scores from the initial to the final stages, indicating substantial improvement in students' ability to conceptualize and prioritize project goals. The collaborative mind maps consistently scored higher than the initial individual maps, highlighting the positive impact of collaboration on idea development. However, variation between collaborative and the final mind map scores suggests differing levels of success in transferring collaborative perspective into individual visualization of the project priorities.

A preliminary thematic analysis of team deliverables further demonstrated a clear evolution in project vision, stakeholder perspectives, and solution details. Teams shifted from a design-centric approach to a more inclusive, stakeholder-driven strategy, effectively integrating sustainability, accessibility, and practical constraints. This progression aligns with the projects educational goals of fostering systems thinking, social responsibility, and critical problem-solving skills.

The findings confirm that mind maps can be effective tools for measuring and supporting student learning in collaborative, project-based environments. The integration of mind mapping within open-ended projects not only enhances student engagement in collaborative work but also shows that the students are open to learning where they become aware of different perspectives and incorporates these perspectives in the project solution.

Introduction

A recent pilot study by Jensen [1] indicated the effectiveness of a collaborative educational strategy introducing first year students to systems thinking, social responsibility and sustainability in civil and architectural engineering projects. The first-year term project was motivated by program faculty concern that upper level students lacked confidence during the ideation phase of their projects. This was noted when students acted as development teams on comprehensive, collaborative projects such as the culminating major design experience. In particular, the steps involving gathering community-based information and prioritizing goals was challenging for the students. This paper expands on the pilot study in assessing the use of mind maps to measure the change in student learning and demonstrating the benefits of introducing engineering topics in a collaborative first-year project.

Mind maps and concept maps can be effective tools to visualize, organize and connect concepts which make these maps ideal for measuring students learning. Mind maps are suitable to create during a shorter, timed session. The mind maps are created around a central idea, branches, subbranches, and connections, but does not require labeled linking connecting lines [2], [3], [4], [5]. The goal, in this project, is to use mind maps to quantify the change in student learning realized during a first-year architectural and civil engineering community-focused, collaborative, term project. A quantitative measure of student learning in a term project may not directly equate to a development of a mindset as systems thinking, social responsibility and sustainability in engineering projects. Yet, the changes to mind maps during the progression of the project is an indicator of the student's change in understanding, perspectives, vision, openness to learning, and effort.

The project is designed around team work and collaborative student learning. Collaborative learning has become a favored active learning module by many students and educators, in particular, when the topics stimulate inspirational discussions and are useful for the future [6]. The effectiveness of collaborative learning has been demonstrated as an engaging alternative to traditional lectures and it can be effective in both in-person and on-line delivery modes [7], [8]. The project deliverables are collaboratively prepared by the student teams.

In this study, three team project deliverables are required including a preliminary proposal, an impact statement, and a project final presentation to stakeholders. The project deliverables are qualitative in nature lending themselves for thematic analysis to identify pattern and themes [9]. Therefore, this study will also be exploring a qualitative method in assessing the change in student learning. Thematic analysis was used to identify the evolution of a team's vision, perspective and solution strategy. The use of only one team for qualitative analysis may not representative of the of entire student body. However, the use of mixed methods for assessing learning enhances the validity of the results [9], [10].

In summary, this study explored whether the implemented educational strategy had positive impacts on the students' learning. Two research questions were explored:

1. Can mind maps measure the changes in student knowledge and perspectives between the beginning and at the end of the project?
2. Can a thematic comparison of student deliverables show how ideas evolve over the course of the project?

Educational Strategy

Introduction to Civil/Architectural Engineering is a 1-credit first-year course, and the students take it in their fall semester. This course aims to provide a general introduction to various types of projects, subdisciplines and stakeholders within the industry. The majority of sessions were designed for all students with 20 % of the class content designed and delivered by major. The students are expected to attend the weekly 75-min class meeting and spend about 120 minutes per week to develop reflection statements about topic presentations, local field trips, professional meetings, exploratory research, and project reports and presentations. The semester is 16-weeks in length including a 110-min meeting during finals week.

The course is design around five modules and they are:

> Foundation and Awareness (Weeks 1-5) – serves as an introduction to sustainability, systems thinking, and professional skills through guest lectures and reflections. Topics like social awareness, placemaking, and the intersection of architecture and engineering introduce critical concepts required for the term project.
>
> Skill Development and Applied Learning (Weeks 6-8) - focuses on environmental literacy, circular economy, and life cycle assessment (LCA) to understand sustainable practices. A team-based presentation on making everyday items sustainable help develop collaborative problem-solving skills and using systems diagrams and mind maps to visualize interconnected processes.
>
> Project Launch and Technical Skill Building (Weeks 9-12) – introduces the term project with the local city context. Additional introductory sessions on fields of studies and engineering tools provide technical knowledge directly applicable to the project requirements.
>
> Integration and Ideation (Weeks 13-15) – offers work sessions for creating mind maps and finalizing the conceptual project components. The aim is to foster team-based ideation to align the learned concepts with project deliverables.
>
> Final Presentation (Week 16) – provides the student teams an opportunity to showcase their comprehensive project vision and how they integrate knowledge and sustainability principles in the proposed solutions. Representatives from the city's Planning Office attend and assess the project presentations. A final, individual, project mind map was also created prior to the final presentation.

This educational model has been used for three consecutive years. After the initial year, the team-based project on LCA of an everyday item was added in the second module replacing a team activity on identifying positive team attributes. At the same time, the course integrated learning materials available from Engineering for One Planet Framework [11] to introduce topic areas of environmental literacy, circular economy, and LCA to understand sustainable practices. Further in the third year, visual diagrams of improved product life-cycle of the everyday item was added as a deliverable.

Each year the term project was presented as a Request for Proposal and it aligned with the local city's goals, needs and priorities. The conceptual term projects have included redevelopment of an abandoned mall connected to a new trail system, redevelopment of a multi-system transit center, and re-envisioning the municipal center. As detailed in the course modules, the students were introduced to engineering terminologies, data and concepts such as sustainability, environmental justice data, low-impact development techniques for stormwater management, building/transit systems, and conceptual cost estimation. The project deliverables included a preliminary project plan, an impact statement, and a final conceptual proposal presentation. Example slides from the final presentation from four different teams are shown in Figure 1.

Figure 1. Four examples of first-year engineering student project concepts.

Quantitative Analysis of Mind Maps

The change in student learning was assessed using mind maps that reflected their vision of the project and how the priorities were addressed. Three mind maps were developed:

- Students, independently, developed the first project mind map immediately after their team received feedback on the preliminary plan. This mind map is denoted “Prelim.”
- The team members subsequent collaborated to develop a mind map that reflected the team’s collective vision and priorities. This mind map is denoted “Team”.
- Three weeks later and just before the final presentation, each student developed a last mind map. This mind map is denoted “Final”.

The individual mind maps were typically constructed on Post-It Mini Easels (15” by 18”) or similar, and the team mind map were constructed on regular Post-It Easels (25” by 30”). The students sat at tables to create the individual mind maps, and they stood in groups around the Post-It Easel to create the team mind map. The mind maps were low stake graded assignments.

This study applied a robust mind map scoring system [6] to quantify the scores of the student generated mind maps. The scores are assigned based on the numerical change in numbers of concepts, layers, relationships, cross links, and examples, if applicable. Summary details of the methods are available in references [1] and [2].

A total of thirty-two students were enrolled in fall 2023 and fall 2024. The mind maps were created during class sessions. Twenty-six (26) complete sets of mind maps are included in this study. The scores from the valid mind maps made by students in fall 2023 (10 sets) and fall 2024 (16 sets) were combined for analysis.

The study was approved by the Lawrence Technological University Institutional Review Board (IRB) under the exemption Category 2(i), approval #02323. Informed consent was obtained from all participants.

Table 1 lists the mind map scores for each valid response. The column labelled Δ indicate the difference between the score of the individual student's Prelim mind map and score of the Team's mind map.

Table 1. Mind map scores.

Student #	**Prelim**	**Final**	**Δ**	**Student #**	**Prelim**	**Final**	**Δ**
i	15	106	57	xiv	25	72	48
ii	35	115	109	xv	62	103	64
iii	54	135	18	xvi	73	108	87
iv	58	112	86	xvii	84	89	127
v	40	50	32	xviii	18	48	108
vi	74	179	70	xix	50	42	92
vii	30	90	42	xx	93	86	118
viii	92	236	52	xxi	134	159	-61
ix	29	44	43	xxii	87	99	55
x	89	220	-17	xxiii	58	181	68
xi	78	106	48	xxiv	137	136	5
xii	133	148	27	xxv	88	48	-15
xiii	76	92	66	xxvi	143	134	17

The analysis of the scores before and after the project activities shows that the mean scores of the mind maps increased after the project activities. The Prelim mean mind map score was 73.5 and at the Final mean mind map score was 113.0, suggesting that the term project had a meaningful and positive impact on the students' perspective and evolution on how the project meet the priorities and goals.

The pilot study [1] offers a visual representation of the Prelim and Final mind maps for a student working on the redevelopment of a multi-system transit center from Year 2.

The Q-Q (quantile-quantile) plots of the Prelim mind map scores and the Final mind map scores are shown in Figure 2. The plots suggest that both the Prelim scores and Final scores can practically be modeled by a normal distribution. The minor deviations at the tails are most pronounced in the cases where a few mind maps scored higher. The skewness to the right is slightly higher in scores of the Final mind map compared to the Prelim mind map. Overall, it is statistically appropriate to assume that both datasets are approximately normally distributed.

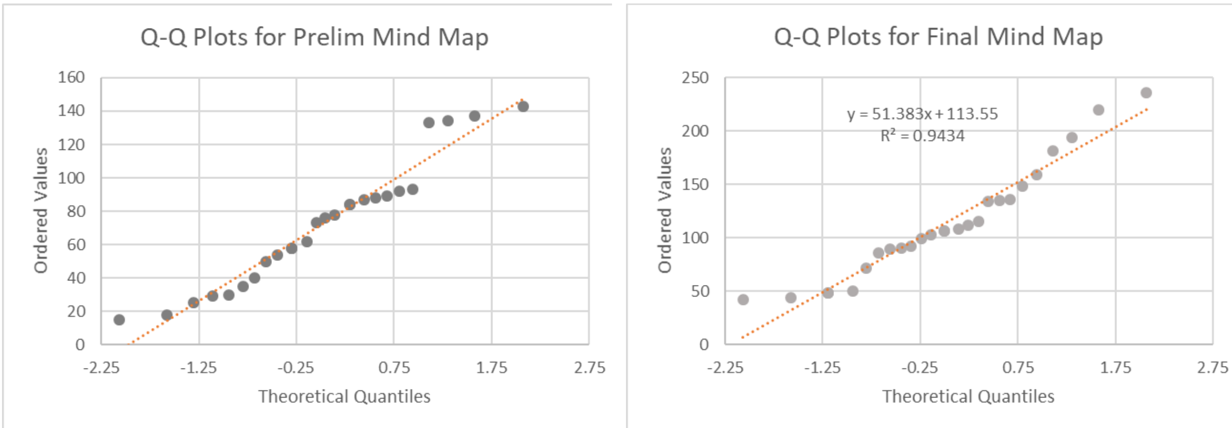

Figure 2. Q-Q plots of the scores representing the Prelim and Final mind map. N = 26.

A paired t-test was performed on the data sets to determine if the project had a significant impact on the individual student's performance. The p-value of 0.00015 was determined. This p-value is much smaller than the typical significance level of 0.05, which means the difference is statistically significant. Therefore, this also suggests that the project had a positive impact on the participants' performance. Figure 3 shows a box and whisker plot of the Prelim and Final mind map scores. The Final scores' box is higher than the Prelim scores' box, showing not only that the median score after increased but also that there is a greater variability in Final mind map scores. Outliers in the final scores (higher-end dots) suggest some participants achieved exceptionally high improvements.

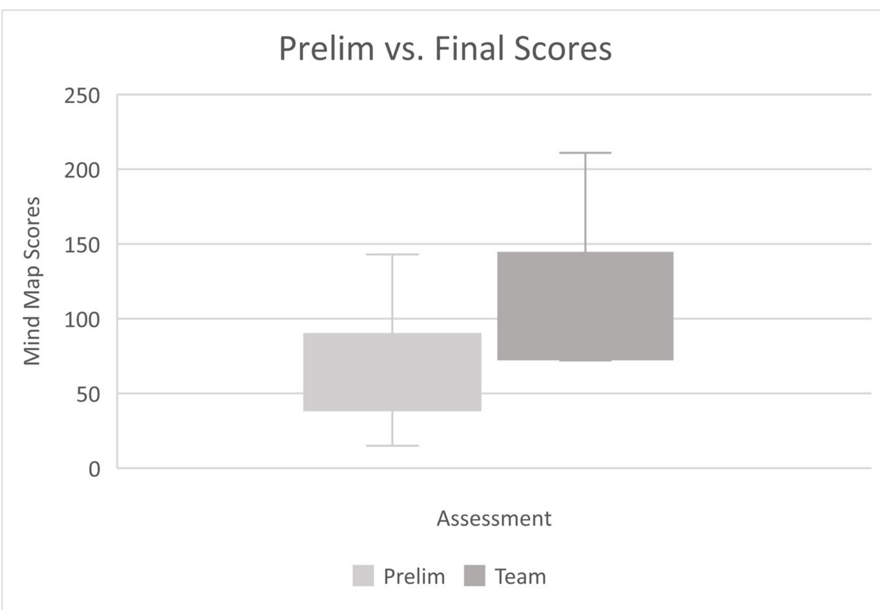

Figure 3. Box and whisker plot of Prelim vs. Final mind map scores. The whiskers show the maximum and minimum scores in each data set and the box shows the middle 50% of the data set. N = 26.

Comparison of the three mind maps provides a measure of the effect of collaboration. Figure 4 compares each student's two individual mind map (Prelim and Final) scores with their team's score (Team). Most students showed an increase in scores from the Prelim to the Final mind map score. This suggests that students learned and improved over the course of the project. The Team mind map scores are noticeably higher than the Prelim scores for nearly all students (88%). This indicates that collaboration significantly boosted the performance in terms of number of priorities and solutions, likely through shared ideas and the group strategizing. Some students' Final scores surpassed their Team scores, suggesting that they applied what they learned during the team activity to their individual work. However, for some students, the Final scores were lower than their Team scores, possibly due to challenges in independently implementing group concepts. In summary, the majority of the students showed an upward trend from Prelim to Team to Final, consistent with continuous learning and improvement.

Overall, the data support that team collaboration led to a significant performance boost compared to individual effort. Further, the Final mind map scores tell that many students were able to internalize and apply knowledge gained from teamwork. However, the variation between Team and Final scores suggests differing abilities to translate team perspective into individual perspective and understanding.

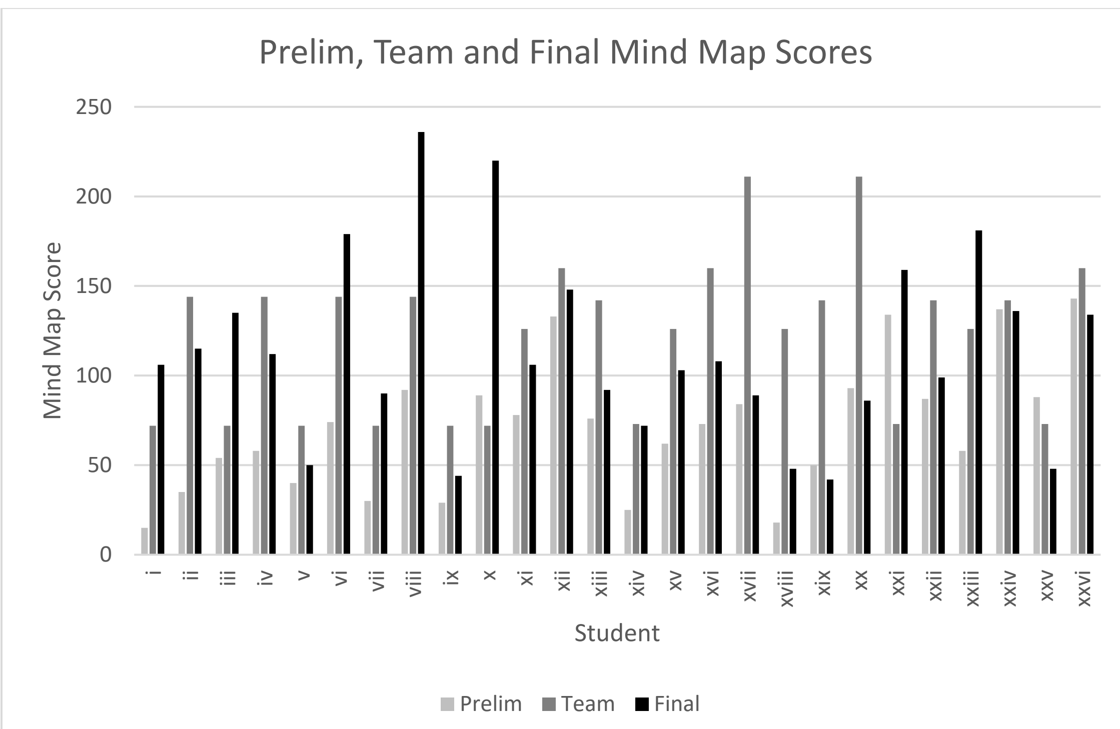

Figure 4. Paired Prelim, Team and Final mind map scores for each student.

Thematic Comparison of Project Team Deliverables for Team 4 of seven Teams

The objective of the qualitative analysis was to determine if a thematic comparison of the student team deliverables show the progression of the project evolution from initial concept ideas to concrete project solution. The three deliverables were:

- Preliminary Project Proposal (Text-Heavy)
- Impact Statement (Text-Heavy)
- Final Presentation (Image-Heavy)

Thematic analysis of the project deliverables from one (Team 4) of the seven teams was conducted using OpenAI's ChatGPT, an AI language model, to identify and compare emerging themes across the project stages [12]. After uploading the deliverables (student names were removed) ChatGPT extracted the text from the documents. ChatGPT was prompted to compare the evolution of ideas over the project duration. In summary, ChatGPT reviewed the extracted content to identify recurring themes, concepts, and ideas. The supervised solution was prompted to focus on three dimensions: vision, perspectives and solution details. The code tracked how these themes evolved across the documents.

Team 4 selected to focus on improvements of the Front Lawn to the city’s government offices, library and recreational areas. The Front Lawn is an important, first impressions, of the municipal complex. The Lawn is frequently used by residents for walking and other recreation and it also serves as location for annual concerts. The specific site goals were 1) pedestrian circulation and access, 2) site legibility and wayfinding, 3) drainage and landscaping, 4) public programming accommodations, and 5) long-term viability. The Front Lawn is about 820 feet long and 450 feet wide. For the term project, sustainability and modern look-and-feel were also added as project priorities. Table 2 presents the results of the thematic analysis.

Table 2. Result of ChatGPT's thematic analysis of project deliverables from Team 4.

1. Initial Proposal

- **Dominant Themes:**
    - **Sustainability**, **flower beds**, **pathways**, **art**, **playground**, and **trees**.
    - Focus is on **design concepts** and physical transformations to enhance **aesthetics** and **environmental sustainability**.

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2. Mid-Stage Impact Statement

- **Dominant Themes:**
    - Emergence of **funding**, **safety**, **community engagement**, and **sustainability** as central pillars.
    - New focus on **transportation solutions**, **inclusivity**, and **social impact**.
    - Transition from design to a more **holistic strategy** involving **social**, **economic**, and **logistical** considerations.

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3. Final Presentation

- **Dominant Themes:**
    - Strong emphasis on **community engagement**, **funding**, **safety**, and **sustainability**.
    - More detailed action items like **events**, **security measures**, **art installations**, and **mobility solutions**.
    - Clear integration of **social impact** and **economic development** alongside sustainability.

Evolution of Ideas

1. **Vision:**
    - **Initial Proposal:** Focus on **physical design** and aesthetics.
    - **Mid-Stage:** Broader focus on **community needs**, **funding**, and **safety**.
    - **Final Presentation:** Balanced strategy integrating **economic**, **social**, and **environmental** goals.
2. **Perspectives:**
    - Shift from a **designer-driven approach** to a **stakeholder-inclusive vision**.
    - Greater emphasis on **public involvement**, **accessibility**, and **safety**.
3. **Solution Details:**
    - Progression from general concepts to **specific, actionable strategies** (e.g., **security systems**, **transportation solutions**, **grant funding**).

The result of the thematic analysis does show that the team experienced the intended learning. ChatGPT does not exactly follow the well-established thematic analysis method proposed by Braun and Clark [10]. Therefore, the author analyzed the three team deliverables following the six phases proposed by Braun and Clark [9] of:

1. Familiarizing yourself with your data
2. Generating initial codes
3. Searching for themes
4. Reviewing themes
5. Defining and naming themes
6. Producing the report.

It is interesting that Braun and Clarke [9] deployed mind maps to visualize the initial and final thematic maps in their case study. This study found very good agreement between the thematic analysis performed by ChatGPT and that by the author. This finding is likely biased and an area for future work using commercial software packages.

This was an open-ended project encouraging diverse solutions. The team is allowed flexibility in how to achieve a solution while balancing integration of innovative ideas for sustainability, accessibility, and inclusion. The project did expect consideration of realistic constraints forcing the teams to consider issues such as budget limits, environmental impact, and social equity.

The thematic analysis of the vision, perspective, and solution details show that Team 4 transitions from "designer-driven approach to a stakeholder-inclusive vision." This aligns with the team initially starting with developing an understanding of the design request, followed by planning of the solution, and finally evaluating if the solution meets the needs of the stakeholders. The author observed that the team members realized that success depends on how well the solution addresses stakeholder needs rather than achieving a specific "correct" solution.

Conclusion

Qualitative and quantitative analysis support the two research questions by demonstrating that mind maps effectively measure changes in student knowledge and perspectives throughout the project and that thematic comparisons of project deliverables reveal how student ideas evolve over time.

The progression from individual to team-based and back to individual mind mapping show how collaboration can enhance individual learning. Team mind maps consistently outperformed the individual Prelim mind maps, emphasizing the value of shared ideas and collective problem-solving. At the same time, the significant increase in the individual student's mind map scores, from Prelim to Final, indicates that students not only gained knowledge but also successfully internalized and applied concepts learned through teamwork.

The preliminary thematic analysis of project deliverables from one of seven teams further supports these findings, illustrating a clear evolution in project vision, perspectives, and solution details. The deliverables moved from a designer-centric approach to a more inclusive and stakeholder-driven strategy, balancing sustainability, accessibility, and practical constraints. This shift underscores the importance of engaging students in open-ended projects that challenge them to consider realistic constraints and diverse stakeholder needs.

Overall, assessment of mind maps can measure student learning in collaborative, project-based environments. The study found that the open-ended project helps students to develop critical thinking and a systems-thinking mindset, and they are open to learning. These skills are essential for students, and later as practicing engineers, to develop complex engineering solutions.

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