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BOARD # 51: Fostering Engineering Enthusiasm and Inspiration: Engaging Through Collaborative Mind-Mapping

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Dr. David Frost

Fostering Engineering Enthusiasm and Inspiration: Engaging Through Collaborative Mind-Mapping

Abstract: This paper explores the effectiveness of cooperative mind mapping in engaging young students planning their career paths. The use of concept mapping has long been recognized as an effective tool for bridging knowledge gaps and promoting a deeper understanding of topics in numerous other fields. It benefits from being a highly active approach to engaging individuals in contemplating and discussing opportunities and challenges. In contrast, many career guidance activities are either based on large group sessions listening to speakers or else one on one sessions with career counselors using structured approaches and thus may often be quite passive in format. The authors are interested in exploring the use of cooperative mind mapping by applying it to engage K-12 audiences, fostering early interest in engineering careers and strengthening communication skills in group settings—both of which are crucial for success in engineering careers. As a result, we elected to perform an exploratory activity conducted during an event organized by an industry led women in technology group at which we were invited to come and speak to 14 female high school students. The authors elected to involve the students in group-based mind-mapping exercises designed to promote creativity, inclusiveness, and collaboration. Participants developed mind maps centered on the theme of STEAM careers, with minimal constraints to encourage independent exploration and diverse interpretations. The resulting mind maps, analyzed using qualitative and graph-based metrics via Gephi, revealed unique thematic and structural differences across groups, influenced by their interpretations of the central topic. One group emphasized foundational STEAM subjects, another focused on the process of pursuing STEAM careers, and a third adopted a broader exploration of STEAM careers. These variations highlighted the flexibility of collaborative mind mapping in capturing participants' perspectives and priorities. The findings underscore the value of this approach in sparking genuine interest, fostering creativity, and strengthening collaboration among participants. By shifting the focus from rigid grading systems to open-ended exploration, collaborative mind mapping proves to be an engaging and effective tool for introducing students to STEAM fields and preparing them for future collaborative work environments. This study advocates for further exploration of tailored prompts and objectives to maximize the potential of mind mapping as an educational tool across various contexts.

Introduction

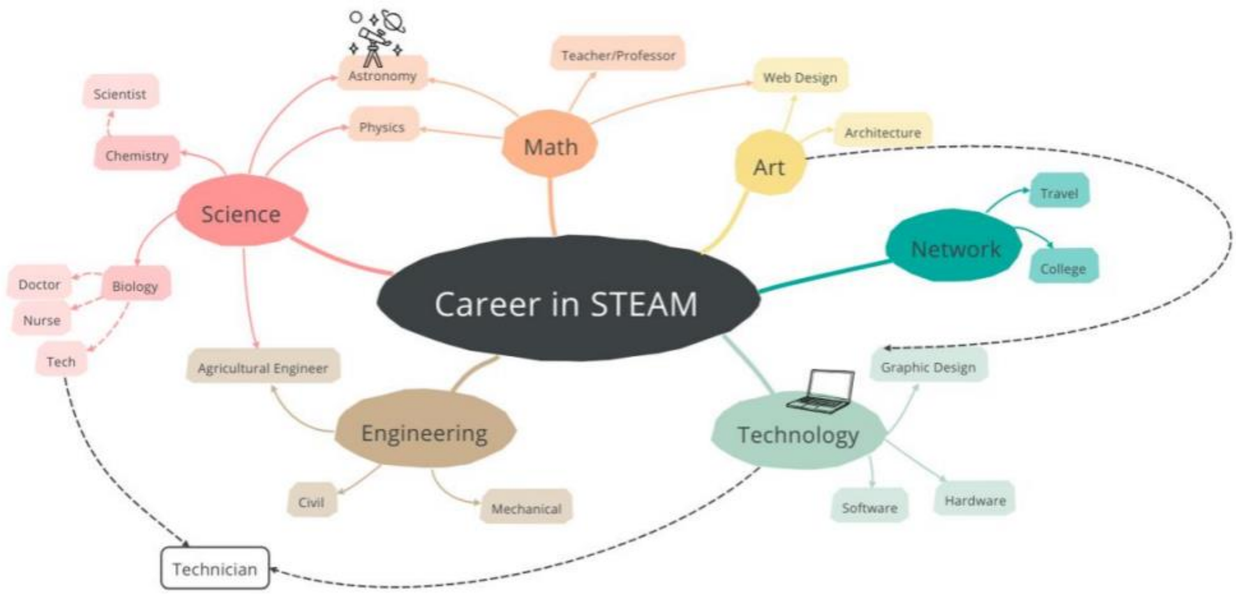
Mind mapping, as a tool for organizing and visualizing ideas, has long been recognized for its ability to capture mental association schemes and explore latent dimensions and connections. This process not only fosters clarity in understanding the relationships between concepts but also highlights the unique aspects of the order and quantity of ideas produced [1]. By preserving the network structures, mind mapping enables learners to engage in the mapping activity and organizing ideas through visual, semantic, and associative relationships, which has led to a more frequent and popular use in academic and educational settings [2]. The educational benefits of mind mapping have been demonstrated across various contexts. Research by [3] revealed that science students using mind maps achieved a better conceptual understanding than those relying on traditional study methods [3], while [4] found that children scored up to 32% higher on memory recall tests when using mind maps instead of lists. These findings underscore the potential of mind mapping as a tool for enhancing both memory and comprehension. Furthermore, mind mapping has been shown to activate both hemispheres of the brain, cultivating intellectual abilities such as abstract thinking, memory, and judgment [4,5]. Active and collaborative learning techniques are also increasingly recognized as essential in education, particularly for fostering shared responsibility and enhancing understanding through group work. In science classrooms, effective collaboration allows students to engage in elaborative explanations, deepen their understanding, and correct misconceptions [4].

Collaborative mind mapping has also been employed in various instructional settings and has shown increasing potential as an educational tool [6]. For instance, Budd utilized mind map exercises in a higher education environment at the University of Minnesota, focusing on the bargaining environment in a labor relations course. In this exercise, each team was assigned a specific year and tasked with creating a mind map of the bargaining environment for negotiations with Phelps Dodge, based on a newspaper-style article [7]. Similarly, collaborative mind mapping exercises have been applied in pre-college education. This approach was implemented in Hong Kong primary science classrooms, conducting a teaching intervention consisting of 20 sessions that incorporated mind mapping and collaborative discussions into the curriculum for the topic "Science and Technology in Everyday Life. [8]" Both studies demonstrated improvements in teaching efficiency and learning outcomes. Collaborative mind mapping has also been proven effective as an assessment tool, serving as a substitute for traditional exams. Concept maps were utilized as a way to evaluate learning outcomes in science education [9]. Despite these successes, prior efforts have primarily focused on specific scientific topics rather than broader themes, such as what constitutes STEAM (Science, Technology, Engineering, Arts, and Mathematics) majors and the pathways to careers in these fields. Existing studies frequently emphasize its use for exploring specific scientific topics with younger participants and involve teaching intervention. There is a growing need to expand its application to broader themes, such as understanding disciplines like STEAM, to foster a more independent and exploratory approach. Building on these insights, this study explores the use of collaborative mind mapping as a tool for engaging high school students in fundamental questions about STEAM careers. Drawing from recommendation to build upon what students already know [10], the study seeks to inspire interest, creativity, and collaboration by reducing teaching intervention and encouraging participants to construct knowledge independently [10]. This approach aims to shift the focus from mastering specific subject matter to fostering curiosity and exploration, creating a more holistic and engaging educational experience.

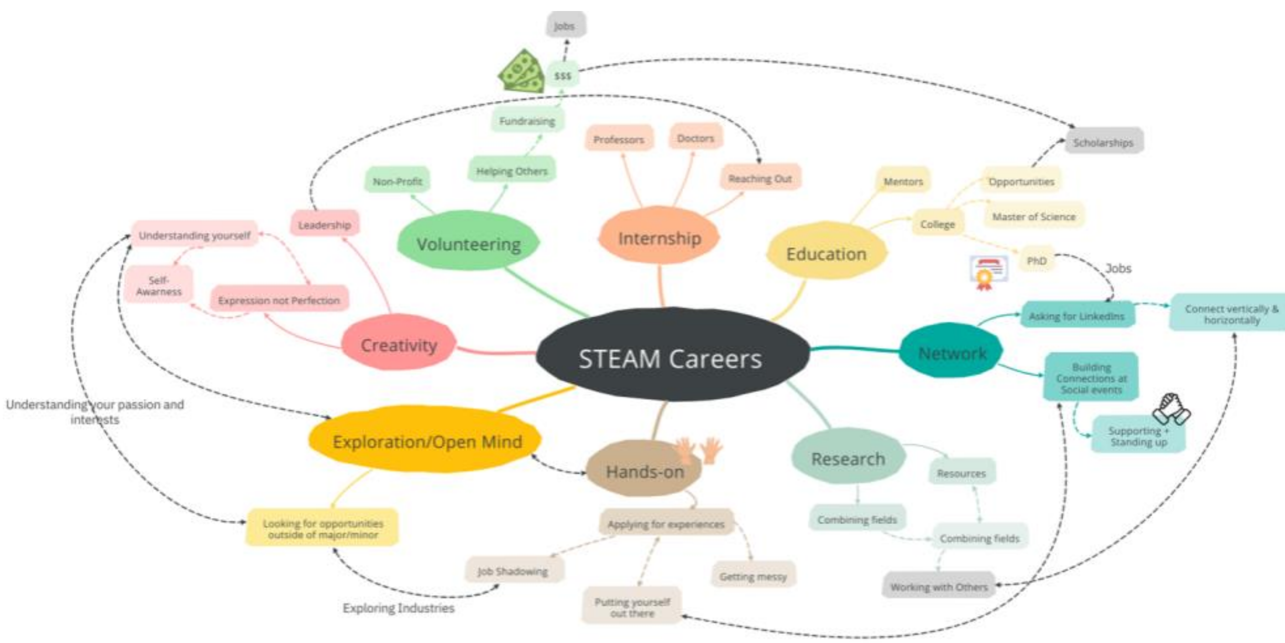
Methodology

As previously mentioned, this study shifts focus to address fundamental questions: "What is a STEAM career?" and "What does it take to pursue one?" Unlike previous research that often required advanced subject knowledge or targeted specific scientific concepts, this approach minimizes the need for prior knowledge and reduces reliance on detailed background understanding. By doing so, participants are encouraged to be more creative and are freed from the fear of making mistakes. Instead of focusing on mastering a particular knowledge area, participants generate mind maps centered on the core principles of STEAM disciplines and general inquiries about these fields. This approach allows for greater flexibility and creativity in the learning process. Additionally, by fostering curiosity and creativity, this study aims to inspire participants' genuine interest in STEAM majors as a whole, offering a more holistic and engaging way to explore careers in these fields.

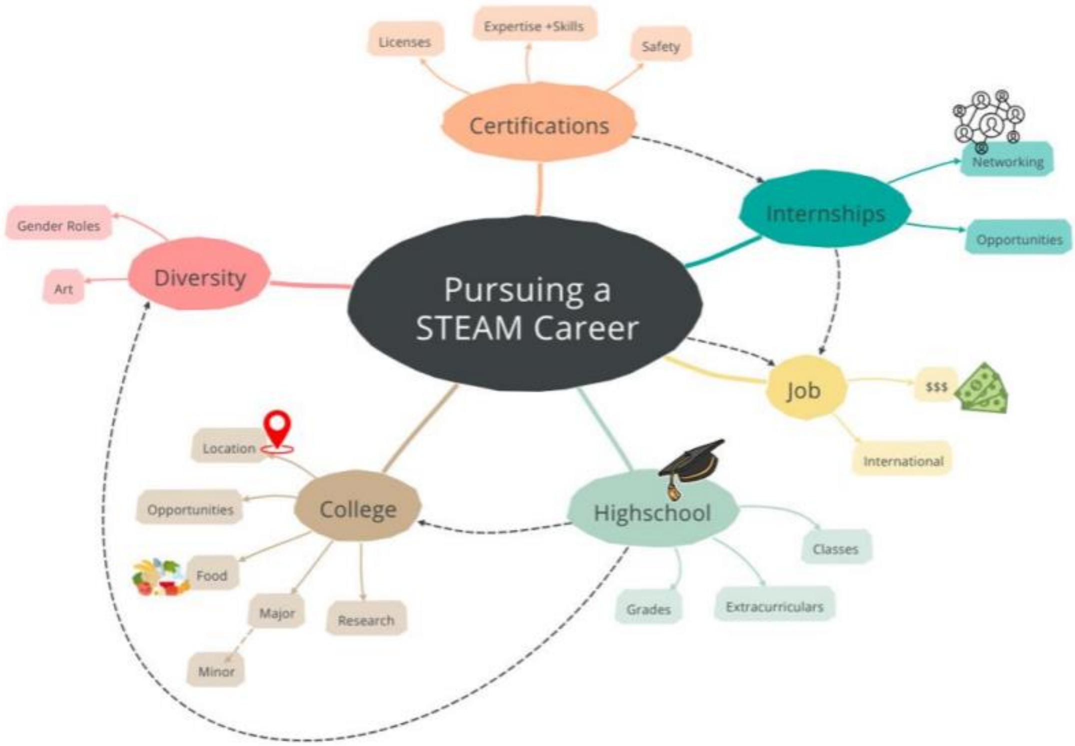
The study reported herein was conducted during a job shadow event, involving 14 rising female high school students ranging from 9th to 12th grade. The mind-mapping exercise took place on the third day of the event, at which point participants had already engaged in shadowing and mentoring sessions designed to provide foundational knowledge about STEAM majors. The 14 participants were divided into three groups: two groups with four members each and one group with six members. At the start of the session, a brief introduction to the mind-mapping technique was presented to the entire group, including a quick demonstration using the topic of traffic conditions in an urban setting. This example was deliberately chosen to be unrelated to scientific or STEAM careers, to minimize any potential bias it might introduce. Following the demonstration, each group was given 15 minutes to create their own mind map with the central theme described as "STEAM careers related." Importantly, the instruction did not specify the exact phrase "STEAM careers" but rather allowed participants to interpret the topic more freely. Interestingly, the groups independently selected slightly different central topic names: "Career in STEAM," "Pursuing a STEAM Career," and "STEAM Career." While the variation in naming was minimal, the emphasis reflected in their mind maps differed significantly, as will be discussed later in the results section. The mind-mapping exercise was conducted with minimal supervision and teaching intervention. Guidance was provided only in response to logistical questions, such as "Can I draw a connection between two branches?" or "Can I add as many links and branches as I want?" This approach aimed to reduce potential bias and allow participants to approach the task independently. The three resulted mind maps are then digitalized and shown below in Fig 1.



Group 1 Career in STEAM



Group 2 STEAM Careers



Group 3 Pursuing a STEAM Career

Figure 1 Mind maps constructed by Group 1 with 6 participants (top). Group 2 with 4 participants (middle). Group 3 with 4 participants (bottom).

Results & Metrics

The evaluation and assessment of the quality of a mind map are complex and highly dependent on the specific goals of the evaluation, as described by [9]. The use of graph terminology to analyze mind maps, adapted from the *Geography of Transport Systems* in 2013, was frequently employed to assess mind map quality [11, 12]. This study utilized several graph-based metrics to evaluate the mind maps, including:

- Degree: The degree of a node was defined as the number of adjacent nodes, or equivalently, the number of unique edges connecting it to other nodes.
- Network Diameter: The network diameter represented the longest shortest path between any two nodes in the graph, reflecting the maximum extent of the network.
- Graph Density: Graph density was calculated as the total number of edges divided by the maximum possible number of edges in the graph, providing a measure of how tightly connected the graph was.

- Modularity: Modularity measured the strength of the graph's division into clusters or communities. It was defined as the number of edges within groups minus the expected number of such edges in an equivalent random network [13].
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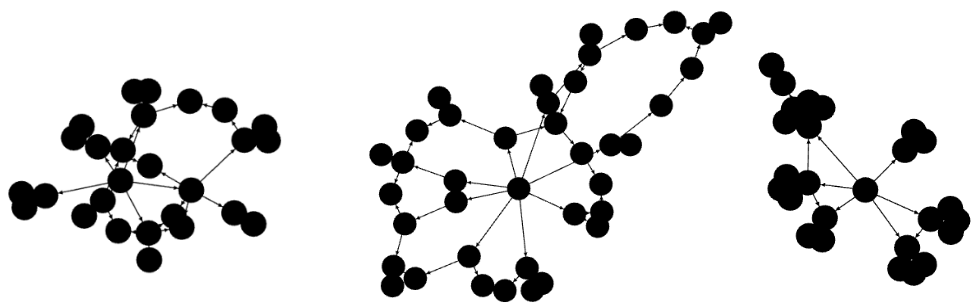
Each mind map was analyzed using the ForceAtlas2 layout in Gephi, an open-source software for visualizing and analyzing network representation [14]. The digitalized and analyzed mind maps are shown in Fig. 2 below. ForceAtlas2 layout was selected for its good performance focusing on nodes connectivity and clustering [15]. The results are summarized in Table 1. As previously discussed, this study did not aim to rank the maps as "better" or "worse" or assign scores. Instead, the focus was on examining how specific metrics reflected the unique characteristics of each map and how student engagement within the respective groups related to these



Group 1 Group 2 Group 3

Figure 2 Mind Maps analyzed using Gephi Graph visualization tool with Group 1 Career in STEAM (left), Group 2 Steam Careers (middle), and Group 3 Pursuing a STEAM Career (right)

differences. Table 1 highlights that Group 2 had the highest average degree and network diameter, yet it did not score as highly in graph density and modularity. In contrast, Group 1 exhibited the highest graph density and modularity but did not lead in average degree or network diameter. These results illustrate distinct focuses and characteristics across the maps.

Table 1 Gephi Analysis Results for 3 Mind Maps

	# of Participants	Central Idea	Average Degree	Network Diameter	Graph Density	Modularity
Group 1	6	Career in STEAM	1.185	3	0.046	0.046
Group 2	4	STEAM Careers	1.231	5	0.032	0.032
Group 3	4	Pursuing a STEAM Career	1.077	3	0.043	0.043

For instance, Group 1, with its higher graph density and modularity, represented a more tightly connected structure where nodes were closely interrelated. This suggested that the group prioritized clustering and linking related ideas, resulting in a denser and more cohesive map. On the other hand, Group 2, which had the highest average degree and network diameter, demonstrated a greater emphasis on branching out and exploring ideas in depth. This branching resulted in longer paths from the central node to terminal nodes, as well as lower graph density and modularity, especially with limited time allowed for developing the mind map. This difference suggested that Group 2 focused on digging deeper into specific ideas rather than clustering them into tightly connected groups. The differences are shown using a “close-up” side to side contrast in Fig. 3. Referring back to Fig. 2, Group 2’s map revealed a more linear structure, characterized by extended branches that reflected its higher average degree and network diameter. In comparison, the maps of Group 1 and 3 exhibited more net-like structures, consistent with their higher graph density and modularity. Similar comparison in these major mind map patterns have been discussed by others that referred to the pattern as “spoke”, “chain” and “net” structure [16]. Though, the line structure referenced in the Group 2 map indicated a more linear arrangement compared to the other groups, rather than being entirely linear, in reality, the Group 2 map incorporated a balanced combination of linear and network structures, which made it effective and efficient for organizing ideas.

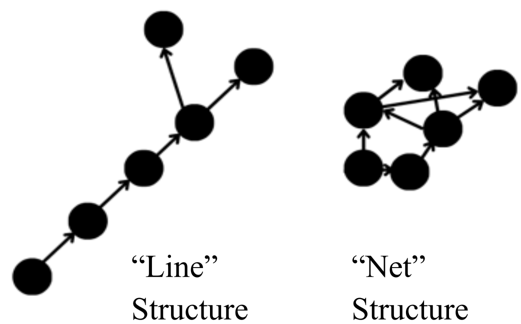


Figure 3 Close-up for a "line" structure (left) versus a "net" structure

The qualitative analysis involved organizing all nodes into four main categories and examining the relationships and connections between nodes and edges. The categorized nodes were color-coded into four categories: primary metrics, enrichment metrics, end goals, and subjects, as summarized in Table 2. Additionally, Table 3 presents all three maps, displaying the categorized, color-coded nodes along with their individual components. More data to demonstrate fostering interest and enthusiasm were collected and is currently being analyzed.

Table 2 Qualitative comparison color-coded dividing into 4 main categories

Primary Metrics	Certifications, Highschool, College, Education
Enrichment Metrics	Diversity, Network, Research, Creativity, Volunteering
End Goal	Internships, Job, Hands-On, Exploration
Subjects	Science, Engineering, Technology, Art, Math

Table 3 Qualitative comparison for 3 groups with color-coded categories

Group 1-Career in STEAM		Group 2-STEAM Careers		Group 3-Pursuing a STEAM Career	
Main Branch	Secondary Branches	Main Branch	Secondary Branches	Main Branch	Secondary Branches
Science	Chemistry	Internship	Professors	Diversity	Gender roles
	Biology		Doctors		Art
	Agriculture		Reaching out	Certifications	Licenses
Engineering	Civil	Education	Mentors		Expert + Skills
	Mechanical		College		Safety
	Agriculture	Network	LinkedIn	Internships	Networking
Technology	Software		Building Connections		Opportunities
	Hardware	Research	Resources	Job	Money
	Graphic Design		Combining fields		International
Network	Travel	Hands-on	Experiences	Highschool	Classes
	College	Exploration	Opportunity		Extracurricular
Art	Web Design	Creativity	Leadership		Grades
	Architecture		Expression not perfection	College	Research
Math	Teacher Professor	Volunteering	Non-profit		Major/Minor
	Astronomy		Helping others		Food
	Physics				Opportunities
					Location

Both Group 2 and Group 3 covered three out of the four categories, while Group 1 focused primarily on the "subjects" category. Notably, five out of the six main branches in Group 1's map were directly derived from the acronym "STEAM," emphasizing what each subject entails. This focus reflects Group 1's approach to building upon the foundational elements of the STEAM disciplines. Interestingly, the slight variations in the central topics of the maps, namely the "main title," directly influenced each group's approach to the task. For example, Group 1 used the title "Career in STEAM," which emphasized the actual careers and roles within STEAM fields. This is evident in the inclusion of more specific physical jobs or subjects rather than metrics related to the process of pursuing these careers. On the other hand, Group 3, with the title

"Pursuing a STEAM Career," concentrated more on the process of pursuing a career, as demonstrated by nodes related to internships, certifications, and college. This distinction is further reflected in the structural differences between the maps. Groups 1 and 3 exhibited more net-like structures as shown with higher graph density and modularity analyzed using Gephi. These net structures, in other words, clusters align with their respective focuses.

Since the workshop was conducted as part of a job shadowing event organized by Women in Technology (WIT), participant feedback was gathered by the organizer in a descriptive format rather than through numerical survey data. When asked to rate their overall experience on a scale from 1 (highly dissatisfied) to 5 (highly satisfied), the organizer reported a unanimous score of 5, indicating a high level of satisfaction. In addition, company leaders who presented as sponsor for the event provided verbal positive feedback, expressing that they enjoyed observing and learning from the mind mapping exercise. Participants also responded favorably, frequently identifying the mind mapping activity as their favorite component of the event. According to the organizer, the inclusion of the mind mapping exercise effectively encouraged participants to engage in conversation and fostered greater collaboration among them.

Conclusion Remarks

The study examined the effectiveness of collaborative mind mapping as a tool for engaging students and fostering interest in STEAM careers by asking fundamental problems of STEAM careers instead of scientific questions that need prior knowledge. By encouraging group-based mind map creation, participants were able to collaboratively explore the concept of STEAM careers, reflecting on both the foundational elements and the processes involved in pursuing these fields. The analysis of the mind maps developed from the WIT event was processed using network graphing tool Gephi and revealed that the structural and thematic differences among the groups were influenced by their respective central topics and approaches. Group 1's focus on "Career in STEAM" emphasized specific roles and subjects within STEAM disciplines, resulting in a more interconnected structure with higher graph density and modularity. Group 3's "Pursuing a STEAM Career" explored the process of career-building, concentrating on steps such as internships and certifications, which also led to a net-like structure but with a different thematic emphasis. In contrast, Group 2's "STEAM Careers" displayed a more linear structure, characterized by branching and in-depth exploration of specific ideas, reflected by its higher average degree and network diameter. However, the workshop which results was analyzed was conducted as part of a Women in Technology (WIT) program with exclusively female participants. To complement the findings of this study, a similar collaborative mind mapping workshop is currently in planning process with an all-male participant group.

The findings suggest that collaborative mind mapping can be a useful tool for capturing the perspectives and priorities of participants while encouraging creativity and collaboration. By allowing participants to approach the task with minimal constraints and reducing the emphasis on rigid grading systems, we foster greater uniqueness among participants and inspire more innovative thinking. Based on these initial findings, future workshops are planned to further explore the method's potential in different contexts, including entry-level engineering students brainstorming career pathways to broaden the educational impact of collaborative mind mapping and to promote its deeper integration as a tool for reflection, exploration, and peer-driven learning. Addition of a more formal assessment component in these workshops is also envisaged. Although distinguishing between prior knowledge and information acquired during the workshop is challenging, the results indicate the development of strong connections across various STEAM disciplines, fostering knowledge sharing and collaboration. Future studies could explore the impact of using specific prompts tailored to the intended task or educational goal. Different objectives, such as inspiring interest, planning strategies, or assessing learning efficiency, may require distinct approaches to prompting and encouraging participants to develop their mind maps. It would be beneficial for instructors to carefully design and adapt prompts based on the desired outcomes of the activity, rather than applying a standardized grading system to every mind map. This targeted approach could help optimize the effectiveness of mind mapping as an educational tool for various learning contexts and objectives.

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