The neurocognition of engineering students designing: A preliminary study exploring problem framing and the use of concept mapping

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Grant Nos. 1929892 and 1929896

Background

Concept mapping is an approach to help students explore both problems and solutions in new ways. The graphical structure of concept maps facilitates the visualization of new relationships and elements, illustrated in Figure 1.

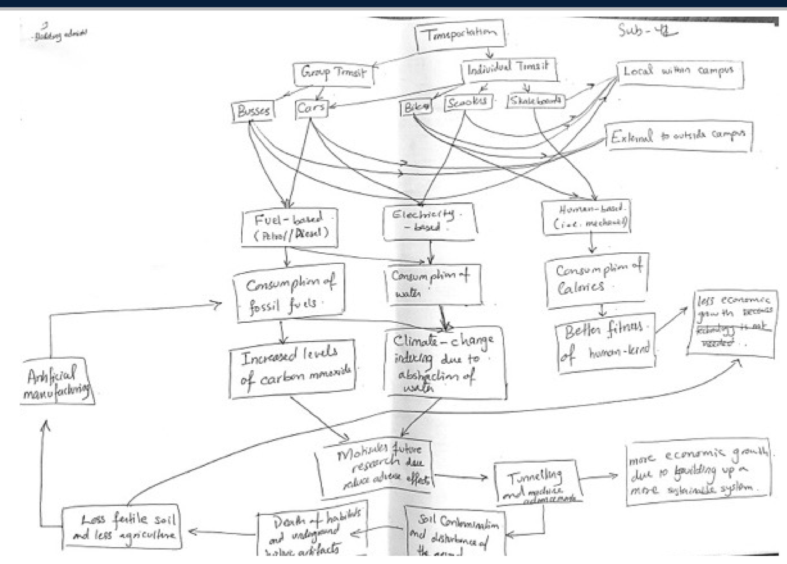

Figure 1: Example of a concept map

The process of graphically representing the connections between complex system components may help enable unique "retrieval paths" for new concepts and help students create new knowledge. What these retrieval paths look like is not well understood.

The purpose of the research presented in this poster was to measure the change in neurocognitive processing that occurs from concept mapping in students' brains. The research question is *what are the effects of concept mapping on students' neurocognition when developing design problem statements?*

We explored changes in students' prefrontal cortex (PFC). The PFC is the neural basis of working memory and higher-order cognitive processing, such as sustained attention, reasoning, and evaluations. Specific regions of interest in the PFC are illustrated in Figure 2.

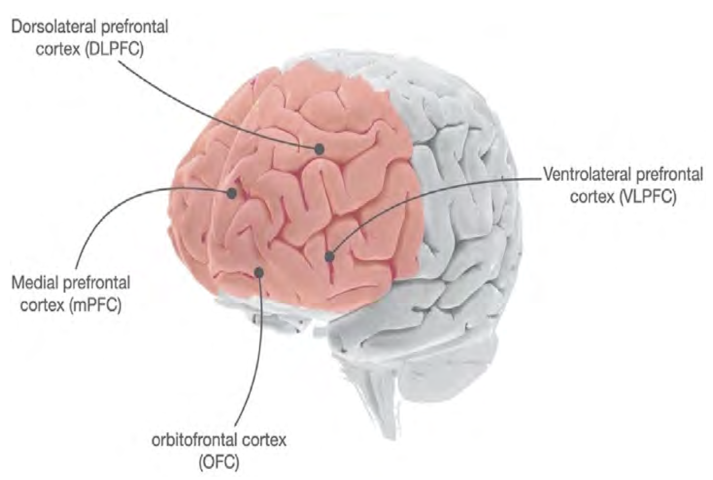

Figure 2: Prefrontal cortex and its sub-regions.

METHOD

All the participants (n=66) in the study were engineering students (undergraduate and graduate) at Virginia Tech. Participants were randomly assigned to the intervention or control group. The intervention group first learned about concept mapping through a tutorial.

Students in both groups were then outfitted with a functional near infrared spectroscopy (fNIRS). fNIRS measures the change of oxygenated (oxy-Hb) and deoxygenated hemoglobin (deoxy-Hb). An increase in oxy-Hb typically mirrors neuronal activity and implies the allocation of resources and nutrients by the cerebrovascular system

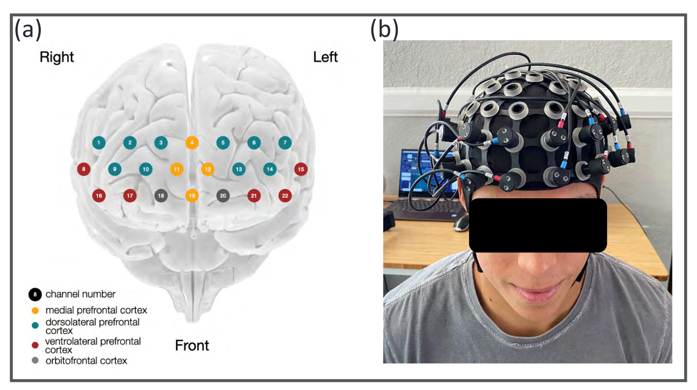

Figure 3: (a) fNIRS configuration (b) a participant.

There were two design tasks and two associated concept maps. One of the tasks asked the intervention group of students to "create a concept map illustrating all of the systems and stakeholders that interact with each other in Patton Hall." Patton Hall is a familiar building on campus. Following the concept mapping task students were told "Virginia Tech has hired you as a consultant. Patton Hall needs to be renovated and your role is to provide a document containing everything you think could be improved in the building."

The second task prompted the intervention group to "create a concept map illustrating all of the mobility systems on campus." Following the concept mapping task, students were told, "Virginia Tech has hired you as a consultant. Mobility on campus needs to be redesigned and your role is to provide a document containing everything you think that could be improved." The order of these two tasks were randomized for each participant. The control group was given the same instructions except for the concept maps.

The neurocognitive activation in the prefrontal cortex (PFC) and its sub-regions was analyzed. Oxy-Hb was averaged for all channels to assess differences in activation for the whole PFC.

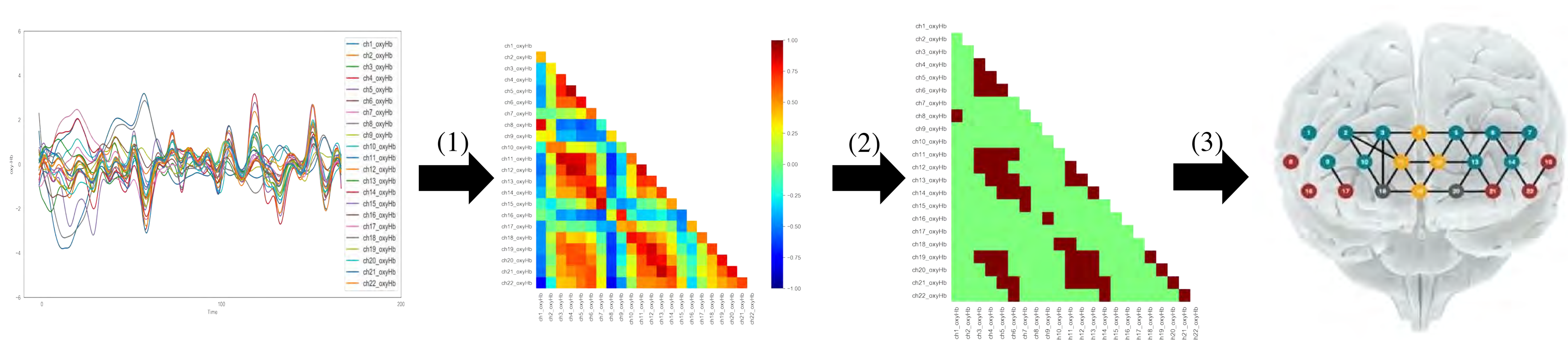

Figure 4: The process of creating brain network graphs, which is a proxy for functional coordination in the prefrontal cortex.

Patterns in brain networks were also compared. Brain networks are a representation of functional connectivity between different sub-regions. Illustrated in Figure 4, brain networks were created using Pearson's correlation, matrices showing the correlation between signal channels measuring the variations in oxy-Hb.

Results

Students who first completed the concept mapping task recruited less oxy-Hb to their left PFC compared to the control group. These student also produced less dense brain networks. The reduction of oxy-Hb in the left PFC and the less dense brain networks was consistent among groups in both design tasks. This is illustrated in Figures 5,6, 7, and 8.

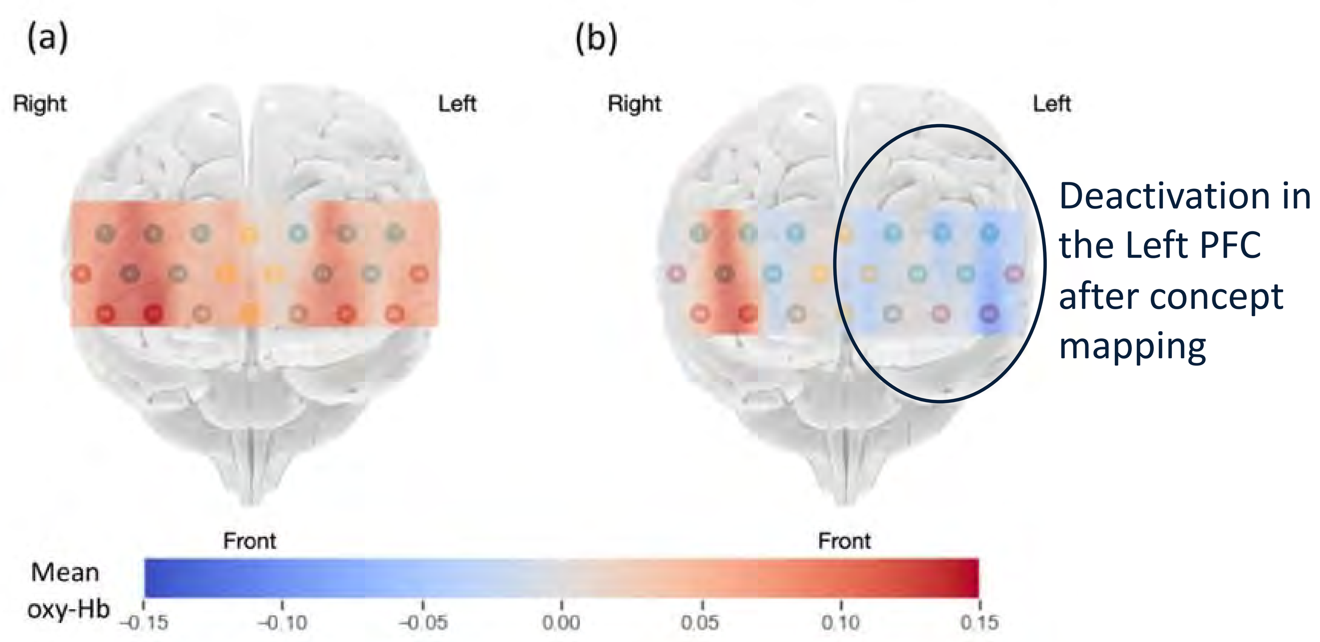

Figure 5: Building system task; (a) Average brain activation for the control group; (b) Average brain activation for the intervention group.

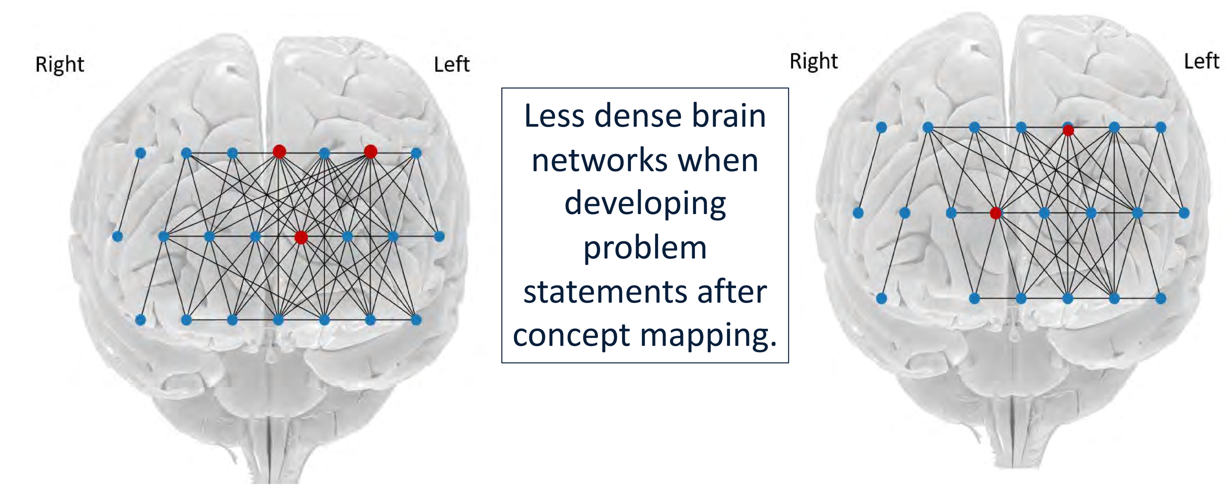

Figure 5: Network graph for the building systems task for the (a) control group and (b) intervention group using a threshold for the correlation matrix of 0.65. Red nodes represent high centrality.

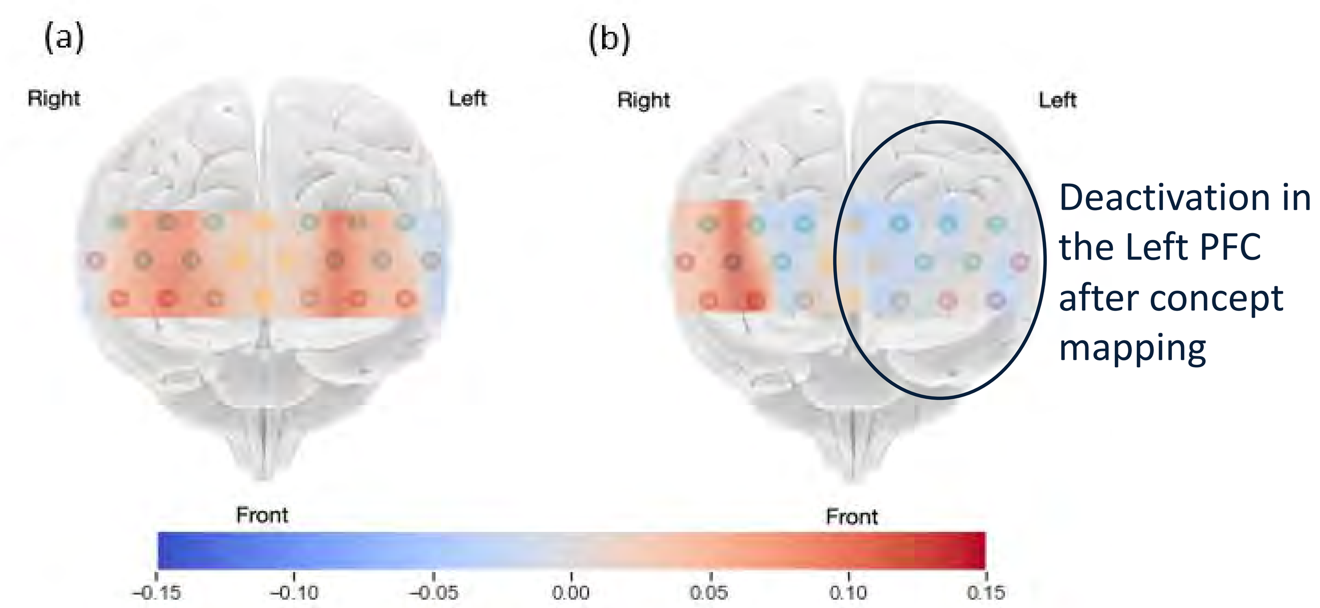

Figure 4: Mobility system task; (a) Average brain activation for the control group; (b) Average brain activation for the intervention group.

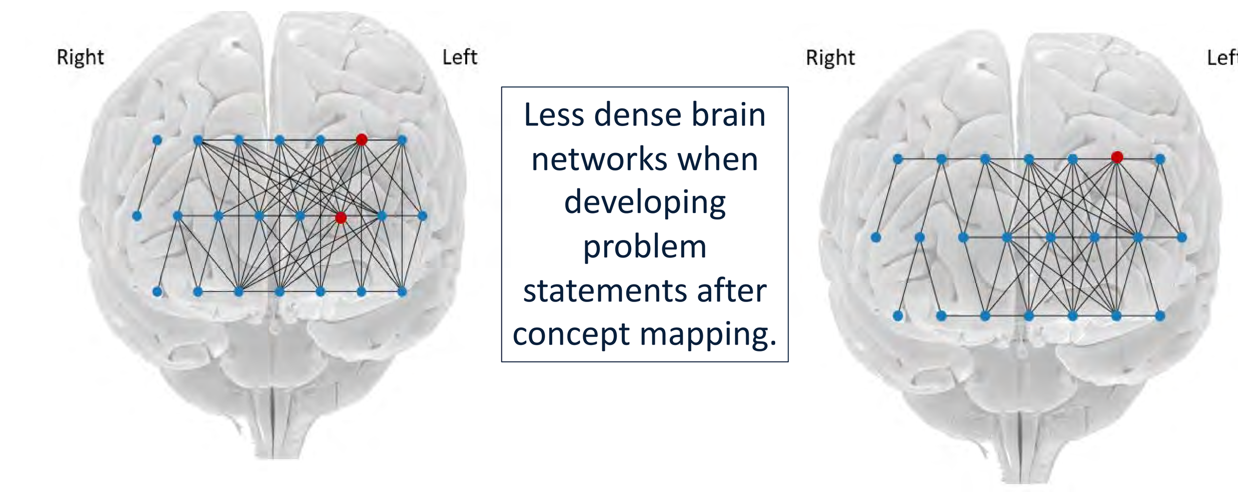

Figure 6: Network graph for the mobility systems task for the (a) control group and (b) intervention group using a threshold for the correlation matrix of 0.65. Red nodes represent high centrality.

The differences observed between groups was significant. Statistical analysis using t-tests found that the oxy-Hb recruited specifically to the left dorsolateral PFC (DLPFC) was significantly less for students who completed the concept mapping task about the building system (t=-2.08, p=0.04; intervention group: M = 0.002, SD = 0.01; control group: M=0.07, SD=0.02) and the mobility system task (t=2.01, p=0.04; intervention group: M=0.01, SD=0.15; control: M=0.05 SD= 0.02). The left DLPFC is generally described with its involvement in making analytical judgments and goal-directed planning [21], [22]. This deactivation of the left PFC as a result from concept mapping may suggest concept mapping aids students' understanding of the purpose and goals of the task before being asked to identify associated problems.

Concept mapping also produced less dense networks. These networks are a representation for functional connectivity in the brain. Network density is a measure of the cognitive resource requirement of the network, and a lower network density is another measure for lower cognitive effort.

Conclusion and Future Research

A possible explanation for the focused and sustained activation in the right PFC and deactivation in the left PFC among the students who completed the concept maps is the process of creating their concept maps aided students' mental organization of information. They were already familiar with the topic of mobility because they had already developed ideas and concepts about it. The use of concept mapping may have helped them facilitate a quicker transition from thinking about one idea to another, which seems to correspond to divergent thinking and sustained elicitation of activation in their right PFC.

Further research is needed to provide the basis for more complete explanations about the meaning of these network differences. The central region, or node, in the medial and left hemisphere of the PFC, might be relevant to the coordination of "retrieval" paths during design. These regions appear to help facilitate functional interaction and act as a control for information flow as it interacts with other brain regions, but network characteristics in neuroscience is an emerging field and how characteristics (e. g., density, clustering coefficient) are correlated to design performance is an area of future research. The intersection of engineering design education, neuroscience, and network analysis as a measure for functional connectivity should be the subject of future investigation to better develop an understanding of how information flows through the brain.

Acknowledgement

This material is based upon work supported by the National Science Foundation under Grant Nos. 1929892 and 1929896. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.