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Assessment of Static Stability Through Concept Mapping

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Introduction

Conceptual understanding is a crucial part of the development of engineering education curricula. As defined by Streveler et al., an “individual’s conceptual understanding of a topic is the collection of his or her concepts, beliefs, and mental models” [1, p. 83]. For engineering students, conceptual understanding is critical in developing engineering expertise. This expertise will be used by practitioners who must adapt their knowledge and apply it to different contexts and to ill-structured, real-world problems [2]. Being able to understand the relationship between different engineering ideas is a skill that students must develop to be successful practicing professionals. Research has shown that this skill is more easily developed in the classroom when students actively participate in learning activities and harder to achieve in passive activities such as attending lectures [3], [4]. This is partially because passive engineering instruction teaches abstract concepts as fixed, well-defined textbook examples that are oversimplified versions of real life phenomena [2]. As such, students often do not know how to apply their engineering knowledge in practice [5], [6]. Several studies have shown that students keep misconceptions or alternate conceptions of class material even after successfully completing these courses [7]. Designing curricula with the goal of building conceptual understanding helps identify misconceptions that can be promptly addressed throughout the duration of a course. Moreover, conceptual understanding is crucial for developing transferable learning [8], which is desired in engineering education.

Many methods have been developed to analyze conceptual understanding within engineering education. One of the most adaptable ones, concept maps, are type of graphic organizer that have often been used to assess students’ mental models and knowledge structures [9], [10]. This paper presents an argument supporting the use of concept maps to assess student understanding of technical knowledge. In particular, this work focuses on the assessment of static stability in aerospace courses.

Literature review

Despite existing literature showing the benefits of teaching for conceptual understanding in engineering classrooms, the aerospace engineering space has been slow to adapt to these teaching practices [11]. In addition, aerospace courses in the middle years are severely understudied compared to capstone and design-focused courses. The current research gaps in the middle years of aerospace engineering include how assessment of conceptual understanding can be implemented in existing courses.

Developed by Novak in the 70s, a concept map is a type of graphic organizer commonly used in education research [12]. A concept map “is distinguished by the use of labeled nodes denoting concepts and links denoting relationships among concepts” [13, p. 415]. Figure 1 from [14] shows the general structure and characteristics of a concept map. In engineering, concept maps can be used to assess the students' understanding of relationships and hierarchies between concepts.

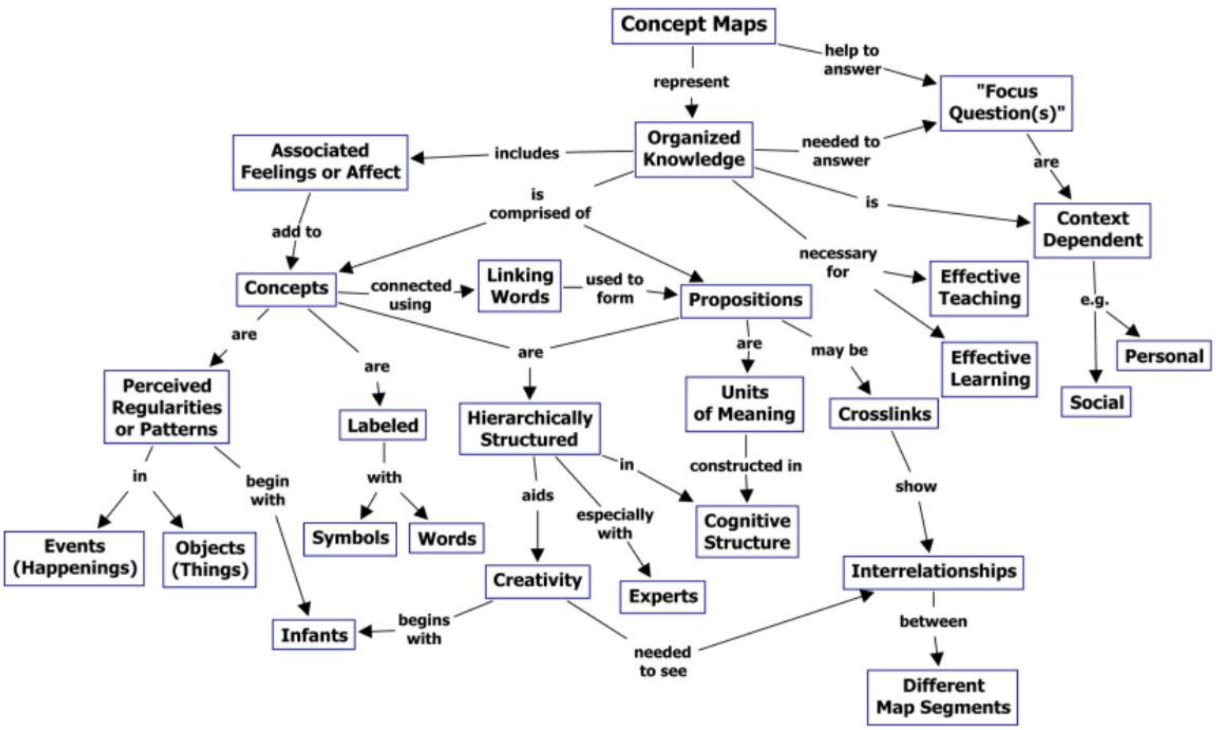

Figure 1: General Structure and Characteristics of Concept Maps [14, Fig. 1]

Since concept maps require students to break down the assumptions of a concept, they have been proven to be effective at distinguishing novice thinking from expert-like thinking [10] as well as serving as a metacognitive device [15]. Using concept maps as an assessment method in class can be a low-stakes way for students to connect the theoretical concepts to more physical representations. Since they are required to draw relationships between concepts, students might have an easier time identifying real-life relationships when working with concept maps compared to other assessment methods. As a metacognitive tool, concept maps allow knowledge "to be portrayed as dynamic and subject to change while preserving a network of interconnected ideas, illustrating the integrated nature of meaning and understanding" [16, p. 22].

Concept maps have also been used as an assessment tool since their conception [17]. Conceptual understanding is based on knowledge organization, and concept maps are graphic depictions of how students organize their knowledge. As such, utilizing concept maps as assessment tools lets, instructors identify incomplete knowledge structures suggested by omissions of important concepts as well as naïve conceptions, "usually indicated by an incorrect linking phrase between two concepts" [18, p. 18]. Concept maps have been used to assess domain-specific knowledge [19], [20], and to assesses learning activities [21]. Finally, compared to other conceptual understanding assessment tools, such as concept inventories, concept maps require less preparation efforts from the instructor and are easier to adapt to new topics. Research on the development and validation of concept inventories shows that, for a concept inventory to accurately assess conceptual understanding, many rounds of validation are needed. This validation is to take place with both experts, to come to an agreement on correct answers, and possible test takers, to verify the understandability of the questions [22], [23]. On the other hand, the development of a concept mapping activity can be developed easily by identifying important keywords and relationships between keywords.

Methods

Participants

This research was performed during the Fall 2023 semester and focused on a flight statics and dynamics course at an R1 university. Since this study aims to understand different levels of student conceptual understanding in the course, all consenting students' work was considered for the study's quantitative section. In total, 24 students consented to have their coursework analyzed for the study. Of the 24 students, four agreed to participate in an interview. Institutional Review Board (IRB) approval for this research was obtained, and participation in the study was voluntary. The researcher reached out to the instructor during a prior semester to pitch the project and verbal consent to proceed with the research was granted.

Data Collection

Concept maps were collected for the Fall 2023 offering of the course to measure student conceptual understanding of aircraft static stability. The students participated in two concept mapping activities for this study. The first concept map was created as a pilot study to familiarize the participants with the process of concept mapping and the results are not considered for the results of this work. The concept mapping activity was coordinated and led by the researcher. The instructor and researcher agreed on a date that coincided with the end of the topic to perform the activity. On said day, the instructor would finish the class material 20 minutes before the start of class to give time for the activity. Then, the researcher distributed handouts containing the instructions, an example of a concept map, and a list of keywords pertaining to the topic of static stability. The instruction and activity document are shown in Appendix 1. The researcher then would give the participants 15 minutes to draw their concept maps following the keywords. The participants were allowed to use the lecture notes, textbook, and any other reference material without interacting with each other. At the 15-minute mark, the researcher collected the concept maps and dismissed the students from class.

Measures and Assessment

The main assessment method that this study utilized was qualitative coding. Prior to this study, the researcher had identified important keywords and relationships between the keywords that were expected knowledge to demonstrate conceptual understanding. For this topic, eight concepts were chosen as potential keywords based on number of occurrences in the lecture notes and recorded lectures as well as their relevance to the topic. Based on these connections, a preliminary codebook was developed. This codebook allowed for a-priori coding on the concept maps. Moreover, in-vivo coding was also performed to capture emergent trends in the concept maps. The final codebook including the expected and emergent relationships is presented in Appendix 2.

Data Analysis

Once the concept maps were coded, cluster analysis was performed in MAXQDA to identify repeating or popular knowledge structures in the students' conceptual knowledge. The variables and formula utilized by MAXQDA to perform the cluster analysis is shown in Table 1. As seen in the table, the matching for the clustering focuses in both the existence and non-existence of common codes. This matching was important for the study because it takes into consideration not only what participants know, but also what they should know and do not.

Table 1: MAXQDA Clustering Strategy

Simple Match $= \frac{A+D}{A+B+C+D}$ Both existence and non-existence are counted as a match. The result is a percentage match.		**Document A**	
		Code value exists	Code value does not exist
Document B	Code value exists	A (# of code values identical in both documents)	B (# of code values that exist only in document B)
	Code value does not exist	C (# of code values that exist only in document A)	D (# of code values that do not exist in both documents)

Results and Discussion

This section presents the results from the scoring of the concept maps as well as the trends found by the cluster analysis. The first result of interest was the utilization of the expected keywords and the keyword relationships. Figure 2 shows the usage percentage of each keyword. Four keywords (Moment, Stability, Horizontal Tail, and Vertical Tail) were present in all the concept maps. Even though all eight keywords were provided as key concepts pertaining static stability, Wing Body, Aerodynamic Center, Center of Gravity, and Angle of Attack were omitted in the concept maps of at least one participant.

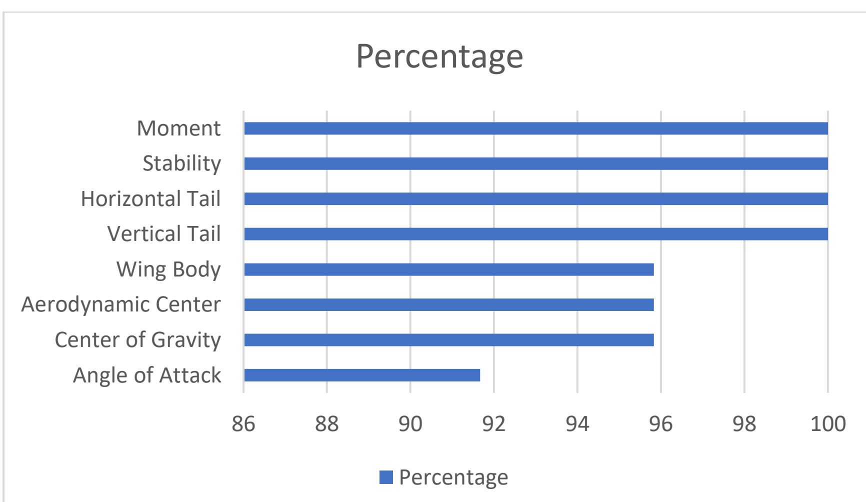

Figure 2: Static Stability and Control Keyword Usage Percentage

Although the prior results show that most participants included the expected keywords, this was not the case for the expected relationships. Expertise in the topic of static stability requires an understanding of the relationships between the Center of Gravity, Aerodynamic Center, and Neutral Point. The coding results from the concept maps showed that only 4.3% of the participants included the relationship between center of gravity and neutral point, 13% of the participants included the relationship between aerodynamic center and neutral point, and 47.8% of participants included a relationship between center of gravity and aerodynamic center.

Another expected relationship was the connection between the center of gravity and the different aerodynamic moments. This relationship was present in about half of the concept maps with 47.8% of the participants including a connection between the center of gravity and some type of moment. From the emergent codes, center of gravity was also related to stability in 47.8% of the concept maps and it was related to the aircraft's geometry 21.7% of the time.

Finally, the expected relationship between the aircraft's stabilizing surfaces and restoring moments saw considerably lower usage than the first two. The aircraft's general geometry was connected to a moment in 56.5% of the documents, which is the highest percentage of codes present for this topic. This was not the case for the specific geometries; the connection between the horizontal tail and pitch moment was present in 26.10% of the concept maps while the connection between the vertical tail and yaw moment was present in only 8.70% of the cases. While a relationship between Moment and Angle of Attack was present in 17.4% of the concept maps, students were unable to identify the relationships between Lift and Moment, and Lift and Angle of Attack. This shows that students are aware of the connection between the angle of attack and the moment generated but are unaware of their connection to lift.

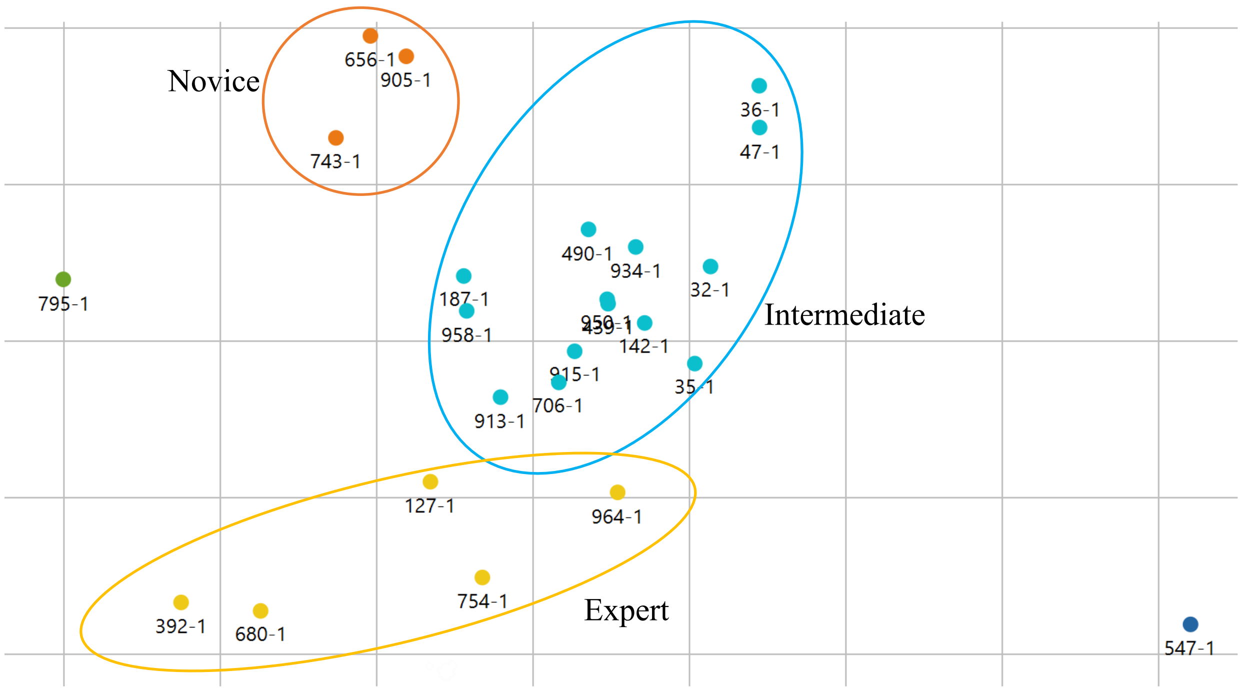

Figure 3: Static Stability and Control Concept Map Clusters

Following the identification of the presence, or absence, of important keywords and relationships in the concept maps, participants were grouped by similarity via cluster analysis. This allows trends to be identified and common mental models to be drawn from these trends. The cluster analysis for the topic of Static Stability resulted in three clusters and two outliers as shown in Figure 3. As described in the methods section, these clusters took into consideration the existence and non-existence of codes between documents as a match to identify similarity. Given that each pair of points was compared across 22 dimensions, once per each code, the clustering shows a relative distance between the documents based on the distance equation shown in the methods section. Due to the reduction to a two-dimensional diagram, this diagram is meant solely as a visualization. During this study, each participant was assigned a random three-digit code to maintain anonymity. Each one of the dots in the figure represents one concept map document and is linked to the code of the participant who generated the concept map. The dots are color coded to represent the cluster that they belong to. As shown in Figure 3, each of the clusters was given a name. These names were chosen based on the characteristics and scores that each group displayed as shown below.

The results of the coding statistics for each group are shown in Table 2. In this table, the first 10 codes (denoted in dark blue) are part of the preliminary codebook used to identify expected relationships. The remaining 13 codes emerged as commonly identified relationships that supported static stability understanding beyond the expected relationships. As the results show, the Expert group had high levels of representation in the expected codes while utilizing some emergent relationships to support their knowledge structure. One of these expected codes, CG – AC, pertained to the static stability requirement that the center of gravity be located forward of the aerodynamic center. As the figure shows, 100% of the participants in the Expert group identified this relationship while only 28.6% and 33.3% of the Intermediate and Novice participants identified it respectively. Unlike the experts, the Novice group focused mostly on emergent relationships that do not fully capture the essence of static stability. The Intermediate group had a mix of both expected and emergent relationships, showing some levels of understanding.

Table 2: Code Presence Percentage per Group

	Expert	Intermediate	Novice	Total
Aircraft - Moments				
Vertical Tail Yaw Moment	40.0%			9.1%
Horizontal Tail Pitch Moment	60.0%	14.3%	33.3%	27.3%
Moment - CG	40.0%	50.0%	33.3%	45.5%
Lift generates Moment				
Angle of Attack proportional to Lift				
Center Relationship				
AC - NP	20.0%	7.1%	33.3%	13.6%
CG - NP	20.0%			4.5%
CG - AC	100.0%	28.6%	33.3%	45.5%
cg-aa		14.3%		9.1%
ac-aa		35.7%	66.7%	31.8%
tail/body-cg	20.0%	21.4%	33.3%	22.7%
aa-stability		7.1%	100.0%	18.2%
ac-stability	60.0%	7.1%	66.7%	27.3%
tail/body-stability	20.0%	64.3%	100.0%	59.1%
tail/body-aa	100.0%	28.6%	33.3%	45.5%
tail/body-moment	40.0%	57.1%	100.0%	59.1%
moment-stability	20.0%	28.6%	33.3%	27.3%
ac-moment		50.0%	100.0%	45.5%
tail/body-ac	20.0%	14.3%		13.6%
cg-stability	60.0%	28.6%	100.0%	45.5%
moment-aoa		28.6%		18.2%
Σ SUM	620.0%	485.7%	866.7%	568.2%
# N = Documents/Speakers	5 (22.7%)	14 (63.6%)	3 (13.6%)	22 (100.0%)

Expert Group

This had a higher level of usage of expected relationships than emergent relationships and was therefore named the Expert group. Figure 4 is one example of a concept map that belongs to this group. This example shows different hierarchies that mirror each other, especially between the branches separating the vertical and horizontal tail. Moreover, concept maps in this group had on average 6.50 (2.43) coded relationships showing their ability to find connections between keywords.

In the first group of expected relationships, 100% of the Expert group participants identified the relationship between Center of Gravity and Aerodynamic Center. As it is the case for the concept map shown in Figure 4, some participants (20%) also identified the relationships between

Neutral Point and Center of Gravity and Neutral Point and Aerodynamic Center. In terms of relationships between the aircraft geometry and moments, 40% of this group identified a relationship between the center of gravity and some moment and had high identification levels between horizontal tail and pitch moment (60%) and vertical tail and yaw moment (40%). Finally, while the relationships between lift and moment or lift and angle of attack were not present in this group, 100% of the participants identified that the geometry of the aircraft was connected to the angle of attack. This indicates that some of the underlying knowledge for the expected relationship is known.

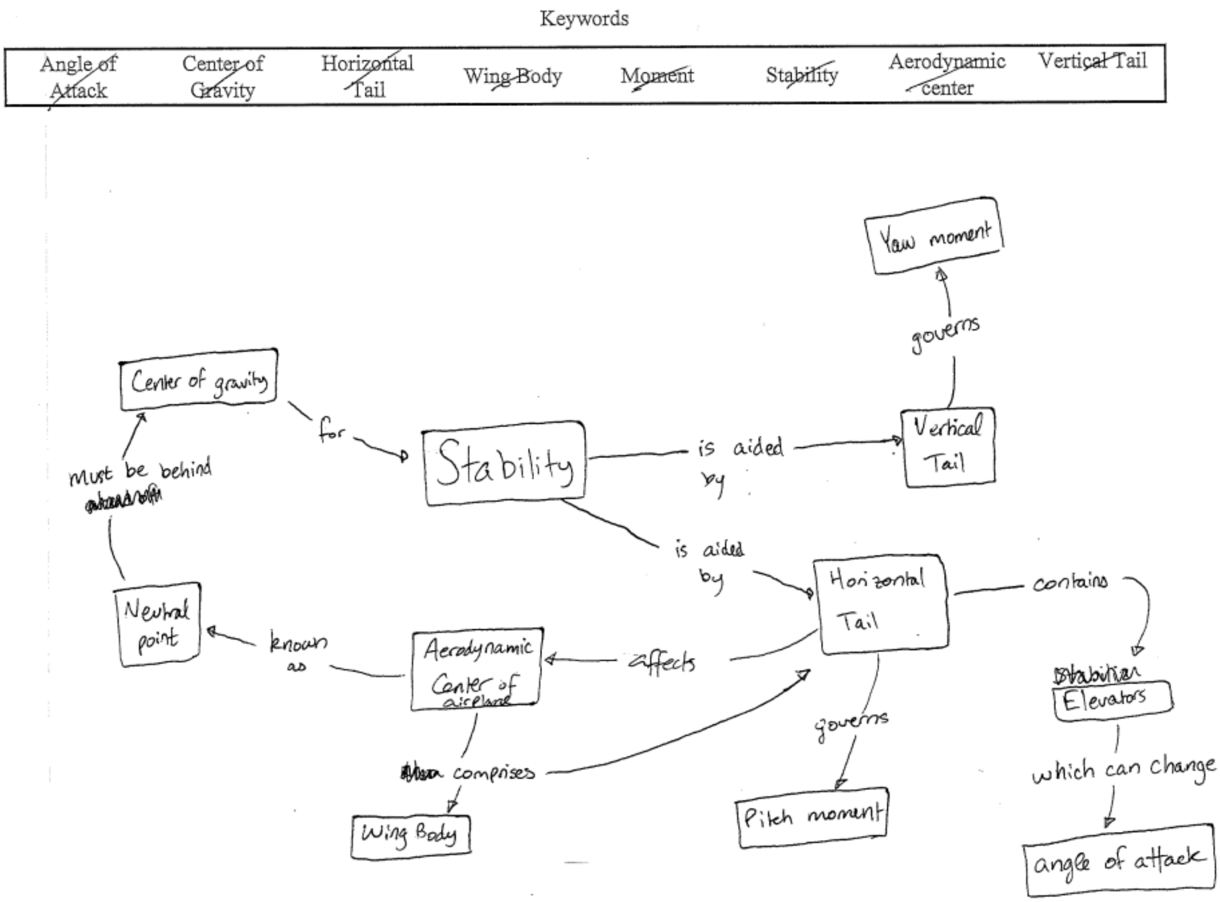

Figure 4: Example of Expert Group Concept Map

Intermediate Group

The second group showed a tendency to miss some expected connections and keywords while still presenting enough knowledge to show understanding and therefore was named the Intermediate group. Figure 5 below is one example of the concept maps that belong to the Intermediate cluster. As the figure shows, the map is organized in a complex structure that includes different hierarchies. This is one of the maps in which there was a term missing. Although Center of Gravity was provided as one of the guiding keywords, this participant did not choose to use the term. As discussed previously, Center of Gravity was a key term for the first and second set of expected relationships for this topic.

In terms of the expected relationships, this group did not show high levels of utilization on most of them. For the center relationships, the highest connection was between the center of gravity and aerodynamic center at 28.60%. In contrast, 50% of this group identified a relationship between the center of gravity and moments and 57.10% identified a general relationship between the geometry of the aircraft and moments. For the specific geometry relationships, 14.30% mentioned a connection between the horizontal tail and pitch moment but no participant in this group mentioned the relationship between the vertical tail and yaw moment. Unfortunately, 83% of the missed keywords were part of this group.

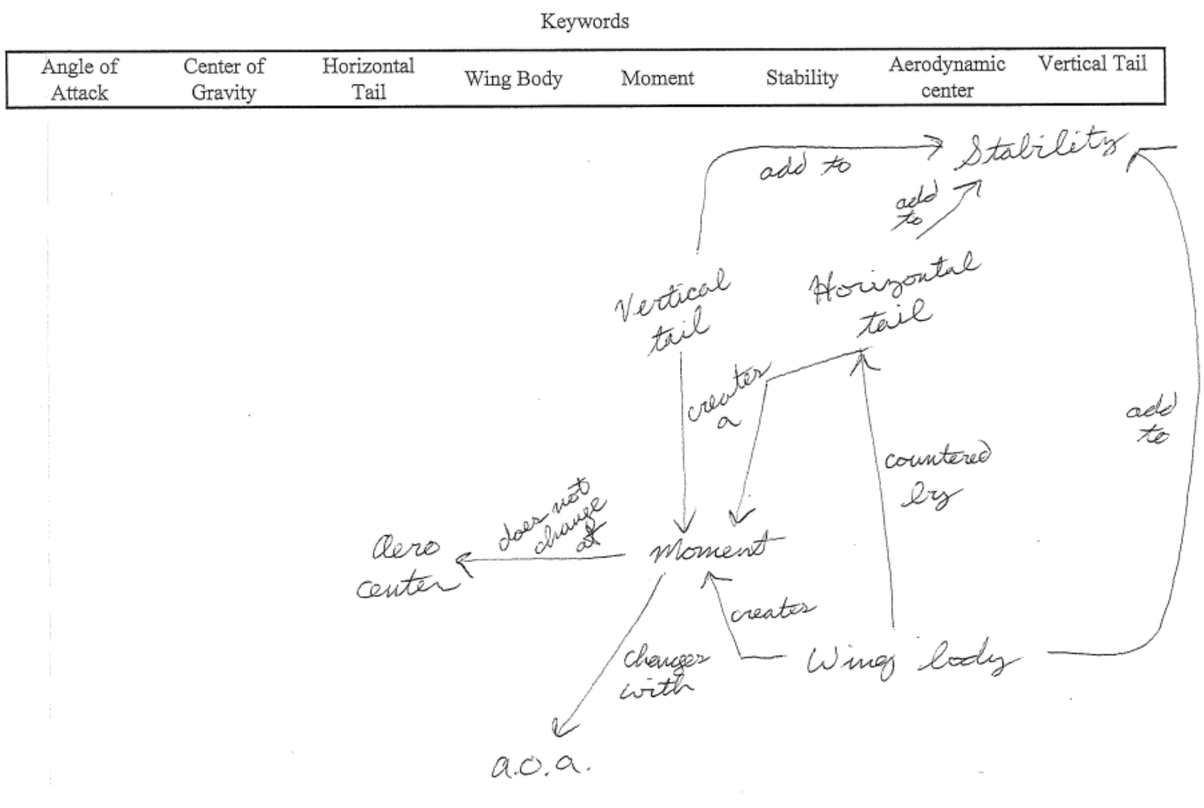

Figure 5: Example of Intermediate Group Concept Map

Novice Group

The final group to be identified from the cluster analysis showed the most breadth of connections but also the greatest number of mistakes and therefore was named the Novice group. Figure 6 is one example of a concept map that belongs to this group. This example shows different hierarchies that are not related and don’t form a cohesive picture. Moreover, as seen in the example, the links between keywords are vague and do not fully explain the relationships the aim to represent. Concept maps in this group had on average 8.67 (0.47) coded relationships showing that participants were eager to draw connections even when the relationships between keywords were unclear.

In the first group of expected relationships, 33.30% of the Eclectic group identified a relationship between the center of gravity and the aerodynamic center and between the aerodynamic center and the neutral point. Similarly, 33.30% identified a relationship between the center of gravity and some moment and between horizontal tail and pitch moment. None of the members identified a relationship between vertical tail and yaw moment. Finally, in terms of the angle of attack, none of the participants in this group included any of the expected connections but 100% of them agreed that angle of attack was related to stability in general.

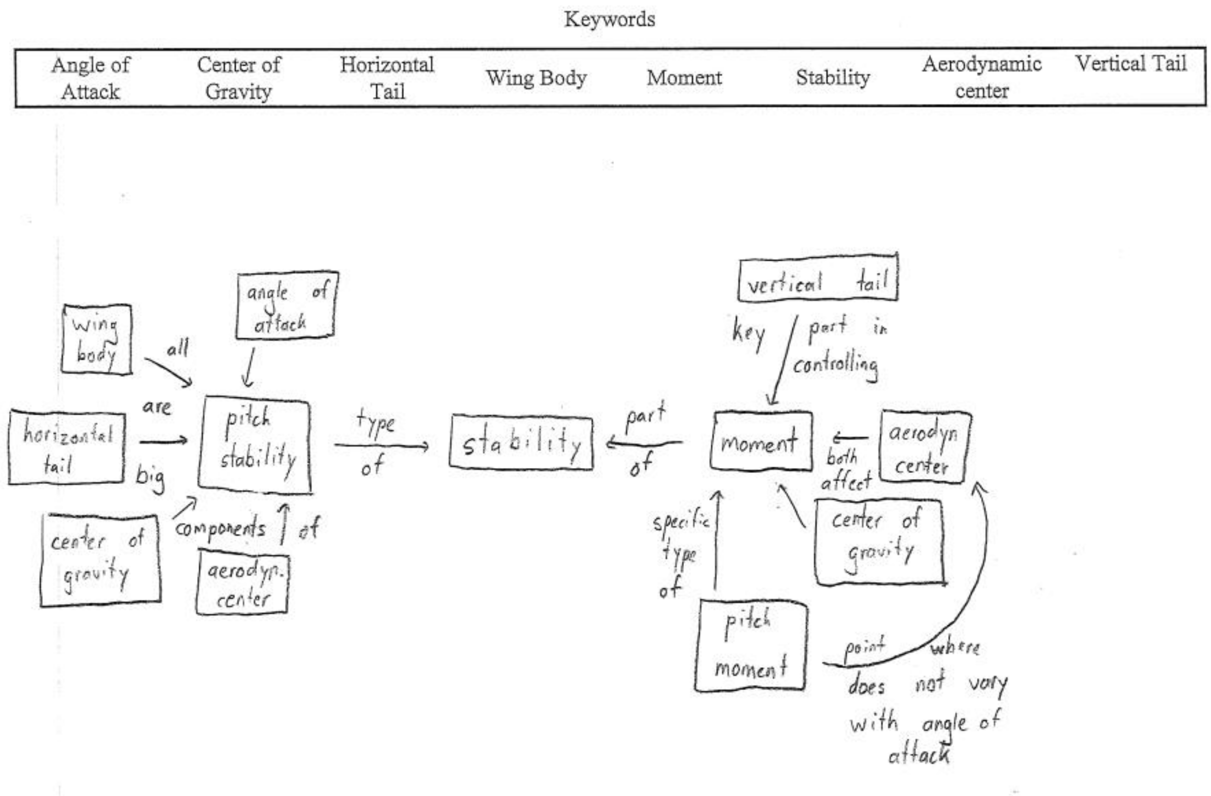

Figure 6: Example of Novice Group Concept Map

These results show that, even though each student has their own unique understanding of the course, trends amongst these mental models can be found. Based on these trends, we can identify points of support that can benefit the overall class. For example, it is concerning that no student was able to identify that the angle of attack influences restorative pitch moment because it leads to a change in lift. The angle of attack was also the least utilized keyword and only 18.2% of the students connected it to static stability. Similarly, with only 27.3% and 9.1% of the participants being able to connect the horizontal and vertical tail to pitch and yaw moment respectively, this activity showed that connections between the physical characteristics of the aircraft and aerodynamic responses must be reinforced.

Finally, even though the individual concept maps did not receive a score, this activity showed its potential as a formative assessment tool. This work shows that concept maps can be adapted to technical topics as a means of assessment for conceptual understanding. Even though the activity required the researcher to have prior knowledge of the topic of static stability, it did not require much time and effort to develop. More importantly, it did not require expertise in assessment development techniques.

Conclusion

The results from this work show that, even though students are experiencing the same course, they form individualized mental models of the knowledge. In the case of static stability, students had a hard time connecting the physical characteristics of the aircraft to the aerodynamic responses. Moreover, this works show that concept maps can be adapted to be assessment tools of technical topics. By utilizing concept maps as a tool for formative assessment, the researcher was able to identify clear gaps in the students' knowledge of static stability. This work is part of a larger study pertaining to the development of conceptual understanding of atmospheric flight mechanics topics. This study serves as a blueprint for formative assessment of conceptual understanding in aerospace engineering middle-year courses. Therefore, future work includes similar analysis of other flight dynamics topics (linearization, and longitudinal and lateral-directional dynamics) as well as a comparison of student and instructor mental models. By focusing on understanding the development of the students' conceptual models of atmospheric flight mechanics topics, it is possible to design courses that are better suited to developing robust understanding.

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Appendix 1: Concept Map Activity Instructions

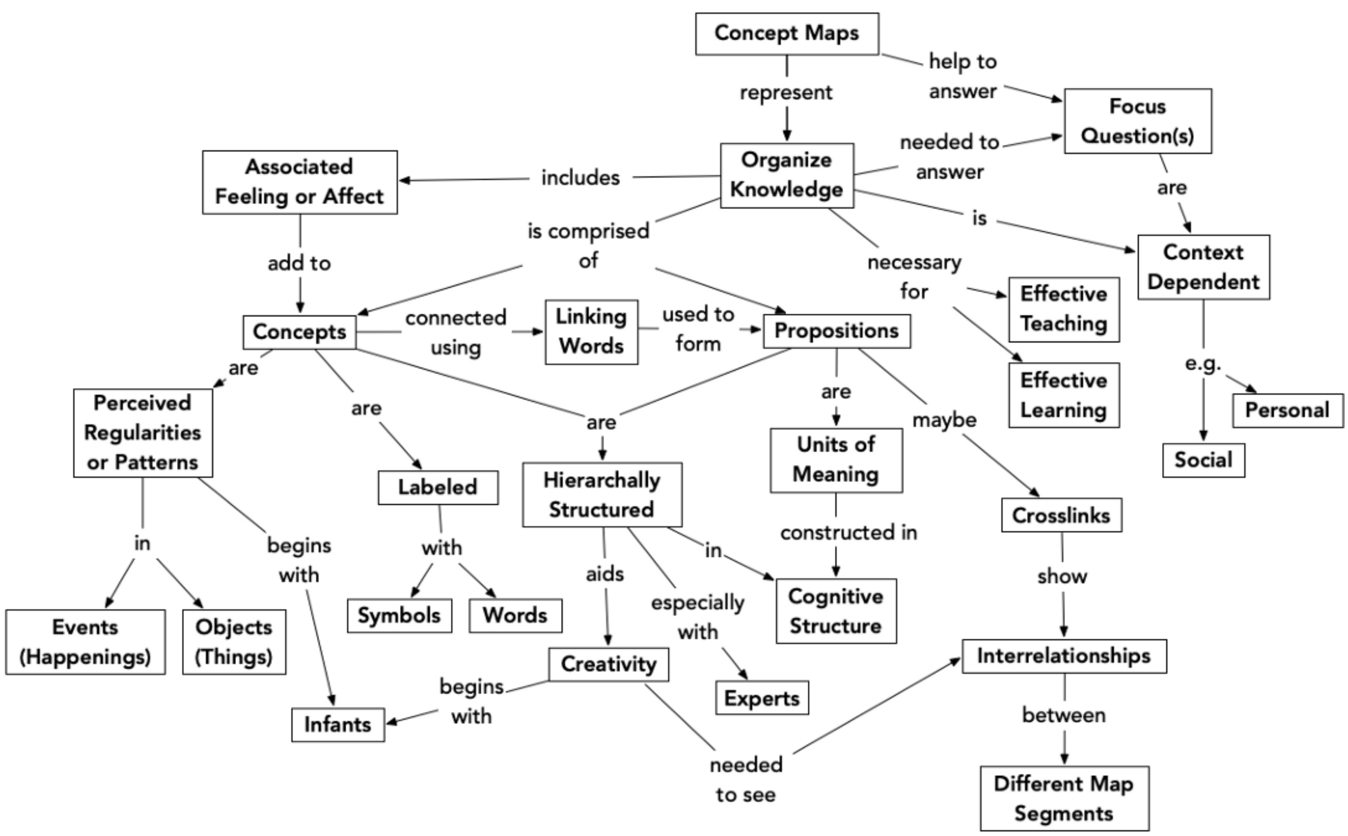
Name ____

Instructions:

In the next page you will be asked to develop a concept map for Topic 0 of this class. You will be given some key words to help you start your concept map. You don't have to use all the keywords if you don't want to. You will most likely have to add keywords of your own that you feel are important to understand the topic. Remember these four things you need to make a concept map:

1. Keywords (either the ones given or your own)
2. Links (preferably with direction)
3. Linking words (keep them short)
4. Propositions (Concept → Link → Concept reads like a phrase)

An example of a concept map about concept maps is presented for your reference:



Keywords

Angle of Attack	Center of Gravity	Horizontal Tail	Wing Body	Moment	Stability	Aerodynamic center	Vertical Tail

Appendix 2: Codebook

	Code	Sub-Code	Relationship
Expected	Aircraft - Moments		
Expected		Vertical Tail Yaw Moment	vertical tail produces a restoring yaw moment
Expected		Horizontal Tail Pitch Moment	horizontal tail produces a restoring pitch moment
Expected	Moment - CG		moments happen around the center of gravity
Expected	Lift generates Moment		lift generates a moment
Expected	aa proportional to Lift		the angle of attack is proportional to lift
Expected	Center Relationship		
Expected		AC - NP	the aerodynamic center of the entire aircraft is known as the neutral point
Expected		CG - NP	the center of gravity must be located ahead of the neutral point for stability
Expected		CG - AC	the center of gravity must be located ahead of the aerodynamic center for stability
Emergent	cg-aa		the center of gravity is related to the angle of attack
Emergent	ac-aa		the aerodynamic center is related to the angle of attack
Emergent	tail/body-cg		the tail/body configuration determines the location of the center of gravity
Emergent	aa-stability		the angle of attack is related to static stability
Emergent	ac-stability		the location of the aerodynamic center is related to static stability
Emergent	tail/body-stability		the tail/body configuration affects static stability
Emergent	tail/body-aa		the tail/body configuration affects the angle of attack
Emergent	tail/body-moment		the tail/body generate aerodynamic moments
Emergent	moment-stability		the aerodynamic moments affect static stability
Emergent	ac-moment		the moments around the aerodynamic center equal 0
Emergent	tail/body-ac		the tail/body configuration determines the location of the aerodynamic center
Emergent	cg-stability		the location of the center of gravity affects static stability
Emergent	moment-aoa		the angle of attack affects the aerodynamic moments