Work in Progress: Improving Problem Solving Performance in Statics through Body-Centric Talk

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***Abstract* - Solving of multi-faceted, complex problems demands students to be self-guided in drawing upon conceptual knowledge. Here we summarize an initial study of the effectiveness of inducing talk about bodies and their relations to forces; the conceptual structure of Statics suggests the potential benefit of this approach. Protocols (written and spoken) are obtained for students solving problems both before and after instruction. Instruction consists of responding to questions about bodies and forces followed by an expert response. Solutions and protocols are graded and coded, respectively. Based on limit data, body-centered talk appears to increase solution accuracy.**

Index Terms – Statics, concept, problem-solving, strategy, metacognition

INTRODUCTION

A significant component of engineering education and practice involves problem solving. This paper addresses problem solving in the context of engineering Statics. Students must have conceptual knowledge, but they must also be able to apply that knowledge in the context of the problem solving process. While conceptual knowledge in Statics has received increased focus [1], methods for developing the associated metacognitive skills necessary to solve problems [2] have lagged. This paper presents an instructional strategy for structuring problem-solving in Statics to promote access to and application of relevant conceptual knowledge. The instruction encourages students to keep track of bodies present and the relations between bodies and the forces. To determine the effectiveness of the strategy, students are given problems before and after instruction. Students' think-aloud protocols while solving problems and problem solutions are analyzed.

RESEARCH DESIGN

This study focuses on student ability to analyze problems such as shown in Figure 1; these problems embody many critical concepts in Statics. The student is asked to determine the loads (interactions or forces) acting on the vertical member CDE. A pre-post design was used. Students solve several problems, receive instruction, and then solve additional problems. While solving problems, students are asked to think-aloud. The written solutions are captured with a large digitizing tablet and cordless stylus; a computer program records the time of each pen stroke. The student's speech is recorded digitally and transcribed with time stamps; this allows the written solution and words to be played back in synchrony.

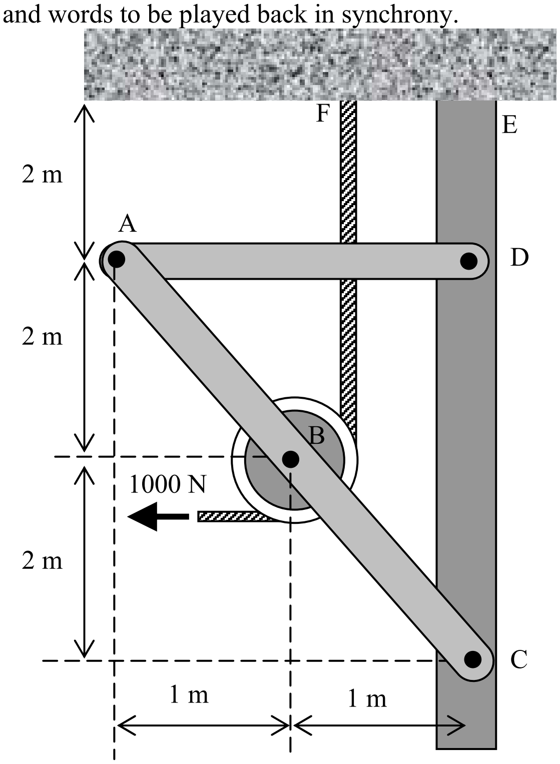

FIGURE 1
TYPICAL STATICS PROBLEM USED IN STUDY.

Instruction for the control group consists of using the same tablet to display problems similar to the test problems, each with a series of candidate free body diagrams. The student is asked whether each free body diagram is correct. Upon student request, a flash movie identifies correct and incorrect portions of free body diagrams. The experimental group sees the same sequence of problems and diagrams; in addition, questions are displayed for the student to answer. The questions target the inter-relations between bodies and forces that are central to the conceptual structure of Statics [3] and include: naming parts that contact a given body, naming parts that exert a drawn force, and determining whether the unknown drawn forces are consistent with the exerting bodies. Upon the student's request, a short flash movie is played in which an expert answers the questions posed. Ultimately the

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experimental group also sees the corrected free body diagrams. Thus, the differing conditions seek to test whether talking and thinking about bodies and forces offers benefits beyond those of merely seeing correct and incorrect examples.

Analysis of the pre- and post-instruction problems consists of grading the written solution for conceptual errors, and coding of the protocol. Meaningful utterances in the student's speech (verbal protocol) are coded according to categories which distinguish body-centered talk (1) from general mechanics reasoning (2), other metacognitive statements (3), mathematical reasoning (4), and restatements or paraphrasing of the problem statement (5). Relative frequencies of different coding categories were computed. In addition, for key parts of the written solution, the verbal protocol was searched to determine whether associated body-centric talk was used.

PRELIMINARY RESULTS

Of eight subjects tested, analysis has been completed for one. Table I displays results for the written solution. The table includes: the number of interactions defined by the student (Num), the fraction of interactions at which unknown forces were incorrectly represented (Rep. Err.), and the number of equal and opposite pairs correctly noted (E&O-R), neglected (E&O-N), and incorrectly noted (E&O-W). This participant left out one interaction in problem B, and had no extra interactions. Note first that the sheer number of interactions has increased after instruction. The student is taking a more comprehensive approach to the post-instruction problems by considering a greater collection of free body diagrams (3 in each of A and B, versus 6 in each of G and H). The fraction of points where forces were improperly represented decreased with instruction. The number of equal and opposite pairs of forces correctly cited by this subject also increased.

TABLE I
PERFORMANCE ON PROBLEMS (OF TOTAL CODABLE UTTERANCES)

Pre-instruction problems					
Prob.	Num	Rep. Err.	E&O-R	E&O-N	E&O-W
A	5	0.40	0	0	1
B	6.5	0.38	1	0	0
Post -instruction problems					
Prob.	Num	Rep. Err.	E&O-R	E&O-N	E&O-W
G	15	0.13	3	2	0
H	15	0.07	6	0	1

The number of utterances and fractions of codable utterances in different categories are shown in Table II. While categories 3, 4, and 5 show the same frequency pre- and post- instruction, the fractions of body-centered talk (1) and general talk related to mechanics (2) changed markedly with instruction, suggesting that body-centered talk can be induced.

The relationship between the written solution and the protocol is shown in Table III. Under the column Inter Yes is the fraction of the total number of interactions for which the body exerting the force was designated. Under the column Err Yes is the fraction of the total number of incorrectly restricted interactions for which the body exerting the force was explicitly designated. In no case did this participant identify the exerting body and then make a representation error for the force it exerted. Thus, naming the exerting body seems to help in avoiding such errors.

TABLE II
FRACTION OF UTTERANCES IN EACH CODING CATEGORIES (OF TOTAL CODABLE UTTERANCES)

Pre-instruction problems						
Prob.	Num.	Cat. 1	Cat. 2	Cat. 3	Cat. 4	Cat. 5
A	68	0.19	0.46	0.29	0.01	0.04
B	56	0.14	0.61	0.21	0.02	0.02
Post -instruction problems						
Prob.	Num.	Cat. 1	Cat. 2	Cat. 3	Cat. 4	Cat. 5
G	113	0.31	0.34	0.27	0.04	0.04
H	74	0.30	0.38	0.24	0.07	0.01

Results related to errors involving equal and opposite forces are less clear. EO(R) denotes correct action, and the category EO(NW) combines EO(N) and EO(W) defined above. Under "Yes" the student named the participating bodies; under "No" the student did not name the participating bodies. The hypothesis that body-centered talk is critical to recognizing equal and opposite forces would be most strongly supported by "Yes" entries under EO(R) and "No" entries under EO(NW). For the single participant, support for this hypothesis is mixed. In any event, data from additional subjects, including some in the control condition, must be collected and analyzed before conclusions can be drawn.

TABLE III
RELATION BETWEEN BODY-CENTERED TALK AND INDIVIDUAL ELEMENTS OF WRITTEN SOLUTION

Pre-instruction problems						
Prob.	Inter	Err	EO(R)		EO(NW)	
	Yes	Yes	Yes	No	Yes	No
A	0.20	0	0	0	0	1
B	0.15	0	0	1	0	0
Post -instruction problems						
Prob.	Inter	Err	EO(R)		EO(NR)	
	Yes	Yes	Yes	No	Yes	No
G	0.53	0	3	0	2	0
H	0.40	0	5	1	0	1

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