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Testing Instructional Approaches in Flipped Engineering Classrooms

Dr. Jia-Ling Lin, University of Minnesota, Twin Cities

Jia-Ling Lin is a research scientist in the STEM Education Center at the University of Minnesota. Her research focuses on two distinct but highly correlated areas: innovative instructional model development and its impact on undergraduate engineering and science learning. Jia-Ling was a scientist specializing nanotechnology and surface science at the University of Wisconsin-Madison. She later served as the director of the Undergraduate Learning Center in engineering at the University of Wisconsin-Madison before moving to Minnesota.

Prof. Paul Imbertson, University of Minnesota, Twin Cities

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Jia-Ling Lin & Paul Imbertson*

STEM Education Center & Electrical and Computer Engineering Department*

University of Minnesota Twin Cities

Abstract

Problem-centered learning in flipped engineering classrooms offers students an authentic learning environment where students are prepared to master content knowledge and skills in problem-solving, team working, and communications. Problematizing content knowledge is employed as an important strategy in instructional design to achieve teaching goals. It brings both benefits and challenges to teaching and learning. This study investigates several issues pertaining to ways of content problematizing. It applies three case studies to identify characteristics in instructional approaches that successfully engage intended learning. Analysis of students' group discussion discourse indicates that cognitive aspects of problems designed for in-class activities play an important role in facilitating learning with conceptual growth, and that social context in developing classroom discourse should be integral to instructional design.

Introduction

Content and delivery are critical considerations for quality instruction design in engineering education. Effective content delivery fosters learners' cognitive abilities in understanding structures and organization of content. In flipped lectures, instructors encounter additional challenges. While acknowledging learners' characteristics and needs, the ways that instructors deliver content so as not undermine students' authority over their own learning is of the utmost concern. We have established a model for quality teaching in flipped classrooms. The model has been applied to and tested in multiple electrical engineering courses over the past four years. [1-4] Learning activities in reformed classrooms are problem-centered and group-based. Results from previous studies have shown that balanced approaches between student-centered activities and instructors' talks, prescribed by the model, lead to positive learning outcomes. Content is presented as problems for in-class learning activities that replace traditional lectures. This engages students in purposeful learning and promotes the development of classroom discourse. Students are encouraged to take ownership and to be accountable for their learning.[1,2] Building on our improved understanding of how students learn and how we support their learning, we proceed to examine instructional approaches for learning content that demands higher cognitive abilities. The current study investigates issues in instructional design concerning learning requirement in flipped lectures.

Background

Flipping classrooms is an emerging instructional method employed in engineering classrooms, which has drawn increasing interest and has advanced as a constructive instructional alternative. It engages students in mastering domain knowledge and developing practical skills for solving real-world problems.[5-8] Students are required to learn content outside the classroom and to work on problems with in-classroom support. Flipping classrooms was perceived as reversing the traditional activities of in-classroom instructor lectures and outside classroom homework assignment when it was first reported. [9] Having recognized the significance of flipping classrooms, which is far beyond the perceived simple "flipping", increasing numbers of engineering educators have embraced the innovative teaching method.[7] Flipping classrooms introduces opportunities as well as challenges to engineering education. It allows us to design instruction that facilitates learning in a variety of ways. Some of these can be both complementary and contradictory at the same time. Students can be assisted with structured and regular tasks to improve course performance. Yet, they can be challenged to learn better by experiencing struggles with key concepts in domain knowledge.[10] The central issue is about identifying the type of instructional approach that maximizes learning potentials in flipped classrooms. The established instructional model focuses on problem-centered learning and encourages students to encounter learning complexities while grappling with key and difficult issues in domain knowledge.[1-4] Content subjects are problematized to engage students in exploring new ideas and constructing knowledge by themselves through group problem solving. Instead of watching instructors working through sample problems or doing homework assignments, students are asked to work on problems posed by the instructor to acquire knowledge, make inquiries, grasp new concept, and design solution models with their peers. Under the model, students are expected to excel in their learning in terms of knowledge retention and transfer through their first-hand experiences in struggling with difficult content knowledge.[1-4, 11] They are expected to move away from passive learning habits and uninspiring experiences. Even though the model, which embraces novel teaching for flipping classrooms with four practices, provides step-by-step guidelines for teaching decisions, the multi-faceted learning nature continues to challenge instructional design. In particular, problematizing content in ways that engage students in productive problem-solving group discussions has proven demanding.

The phrase *problem-centered learning* is used consciously to avoid invoking mistaken identification with problem-based learning and to emphasize teaching practices that problematize the content. Problem-based learning (PBL), originated and now implemented in medical schools around the world, is a systematic approach to preparing medical doctors to be problem-solvers. Covering a variety of problem-solving activities, PBL may be the most significant pedagogical innovation in education in late nineties.[12] PBL has been embraced by engineering educators to prepare engineering students to become skillful problem solvers.[13] However, the pedagogical innovation of PBL employs only one model for supporting problem solving instruction and shows limitations, so variations under PBL lead to inconsistent learning outcomes.[13] Use of the term problem-centered learning allows us to apply an integrated pedagogical model in flipped engineering classrooms for a broader range of teaching and learning objectives. Instruction design for problem-centered learning synthesizes components from several validated models such as problem-solving, inquiry-based teaching, dialogic inquiry, the Lesh Translational Model, etc.[12, 14-16] Design considerations are centered on facilitations for a collection of learning activities including knowledge acquisition, knowledge construction, problem solving, and others, aiming at instructional objectives for conceptual growth, engineering design, and teamwork.

Problematizing content is accomplished by presenting subject knowledge in a format traditionally defined by a problem domain, a problem type, a problem-solving process, and a solution. A problem is unique when it includes "the content, the combination of concepts, rules, and procedures, and the representation". [12] Learners' understanding and goals are thus two key elements in problem solving.[12] A few basic considerations in problem-solving instruction, such as problem categorization, lend us utilities in problematizing domain knowledge. Accordingly, problems are typically divided into two large groups: well-structured vs ill-structured. Well-structured problems involve concepts and rules that appear regularly in subject domains and have a preferred and prescribed solution process for knowable, comprehensive solutions. Ill-structured problems, on the other hand, have multiple solutions with divergent solution processes and require multiple criteria to evaluate solutions. Given varying natures of different problems, the ways that problems are presented to learners understandably affect the ways by which learners understand and solve them. For instruction design contemplations in content problematizing, other challenges occur. For example, presenting a problem that introduces new and unfamiliar subjects to learners, even if it is well-structured with a predictable solution process, can be confusing to some students. It may hinder learning if an apparent numerical solution surfaces, effectively sidestepping the intended learning processes. Problematizing content in the format of ill-structured problems will in general provide students with authentic learning opportunities. Yet, it has the risk of making learning extremely difficult, thus causing frustration.[10] Adapting a balanced presentation between well- and ill- structured problems with contextualized approaches is needed for engaging learning. It will help students overcome barriers in both emotional and cognitive capabilities.

Research Methods

Research questions

The study comes out of a design-based research paradigm and assesses instruction design and delivery in flipped classrooms.[17] It investigates three research questions pertaining to ways of problematizing content knowledge and their influence on learning outcomes: (1) What are the features of content problematizing, which engage learning as intended, or hinder learning resulting in gaps between teaching and learning? (2) What are the techniques needed for content problematizing to mend gaps between teaching and learning? (3) Are there any disparities in learning outcomes under problem-centered learning, and if so, how do we diminish the inconsistency?

Research design and data collection

The study was conducted in the course Electric Drives, one of the three core courses in the curriculum of electrical energy systems. It is offered once every year and has enrollment of about 100 students. Data collected between spring 2012 and spring 2015 include:

(1) Students' verbal discourse while working within small groups on problems posed by the instructor. Student talks were observed by researchers and audio recorded. In spring 2014, the audio recording was on a weekly base.

(2) Students' team worksheets in group discussions during in-class lecture periods and for "mock test" group problem-solving exercises right before midterm exams.

(3) Copies of students' midterm exams. The collected written works were analyzed and referenced in conjunction with the audio data described above.

(4) Two online surveys. One conducted at the beginning of the semester and one at the end of the semester. Two focus group meetings were conducted. One each at the end of the semester in spring 2013 and 2014.

(5) Video recording of the instructor's in-classrooms presentations including contextualized lecturing and talks while interacting with small groups and/or individuals in classrooms.

In this study, we report three case studies that examine the content problematizing method. We analyzed the verbal discourse from six student group problem solving discussions in spring 2014. The activity was a closed-book and closed-notes "mock-test" group problem-solving exercise before midterm exams. Four were before the second midterm (T2), and two before the third midterm (T3). The recorded verbal utterances were transcribed and analyzed. Students' written work was collected and evaluated.

Data analysis

- Coding scheme for discourse analysis was developed based on the revised 2-D taxonomy of instructional objectives for science and engineering teaching.[18] Table I shows the four types of knowledge for discourse content analysis, factual, conceptual, procedural, and metacognitive from concrete to abstract from the taxonomy. Table II characterizes utterance styles with embedded cognitive ability also from the taxonomy.
- Quantifying the occurrence of talk content in terms of the four knowledge types and the five utterance styles was accomplished through frequency counting. The quantitative method is to support qualitative characterizations of instructional design.

- Instructional design rationale, conditions, and techniques are examined in conjunction with classroom discourse and learning outcomes.

Table I. Knowledge Dimension of the Coding Scheme [11,18]

Knowledge Type	Sample Verbal Data
Factual (F): Terminology; Specific details and elements.	*"Isn't P mechanical tau times omega?"*
Conceptual (C): Classifications and categories; Principles and generalization; Theories, models, and structures.	*"So, what if we assume the total power we get is some torque times speed. So that torque is going to be applied by the motor no matter what."*
Procedural (P): Subject-specific skills and algorithms; Subject-specific techniques and methods; Criteria for determining when to use appropriate procedures.	*"We're trying to find mechanical power; we have to use mechanical speed."*
Metacognitive (M): Strategic; Cognitive tasks including appropriate contextual and conditional knowledge; Self-knowledge.	*"I first did it using P(ower) and then added it to the answer and had it wrong." "Oh! That's where I got mixed up. It's not omega synchronous. If you just say omega…"*

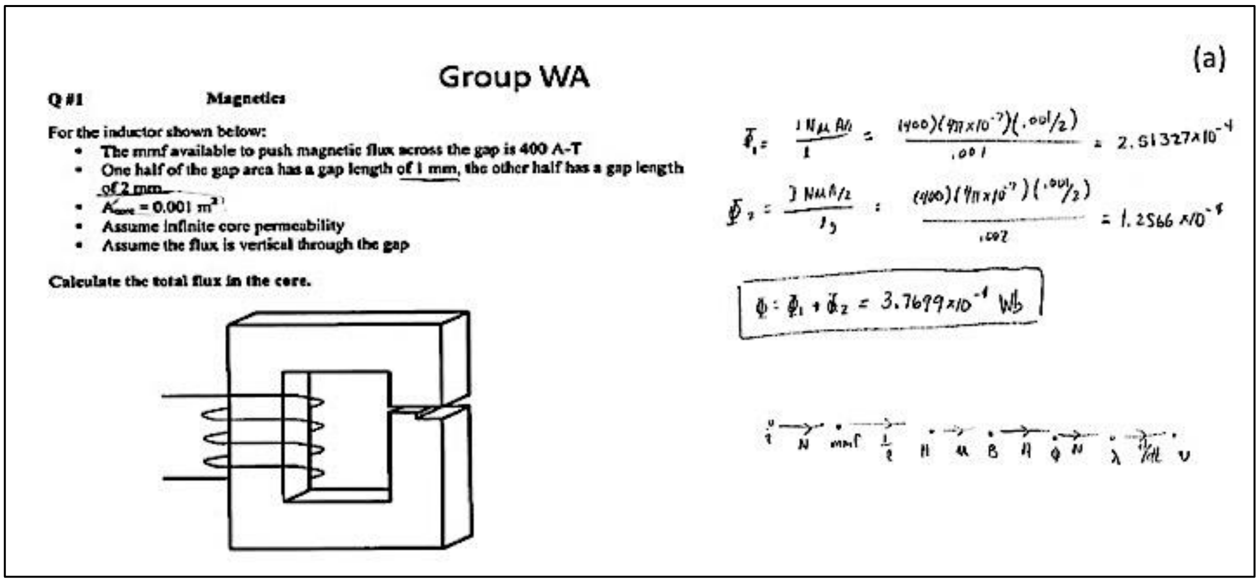
Table II. Styles and Cognitive Relevance of Verbal Discourse in Group Problem-solving[11,18]

Utterance Style	Definition and Structures	Sample Verbal Data	Cognitive processes Relevance
Responding (RS)	Agreeing, Disagreeing, Making a statement, Adding information	*Right. Omega equals 10 times TL…; It's the other K, K_T.*	Remember Understand
Reacting (RA)	Providing explanations and reasoning; Asking questions; Making inquiries for content-specific key concepts for deep understanding; Investigating and exploring new ideas; Critically reviewing and challenging proposals; Purposefully referencing established and credible information for applications and analyses	*The motor is in a steady state.--- If the speed is a constant, does that imply that?--- I don't even think it's a constant. If it's a constant we can say acceleration is 0.--- Yeah, because it's in a series. Or because we are in steady state.---*	Understand Analyze Apply Evaluate Create
Reflecting (RL)	Reflecting for restatement	*I don't know. I'm getting 94. It's probably a calculation error.--- I'm saying one of us did something mathematically wrong.*	Understand Analyze Evaluate
Soliciting (SO)	Inviting for collaborations	*From that can't you figure out the frequency?*	Understand Analyze
Initiating (IN)	Starting a new topic by asking questions, making a statement, exploring, etc.	*K_T is K_{Omega}, right?*	Remember Understand

Results

Results from the three case studies are shown in the following. These case studies compare features of content problematizing and examine ways in which content problematizing engages or hinders learning through students' group discourse analyses. Verbal utterances during group discussions were analyzed in terms of content and style as displayed in Tables I and II. When group discussions focused on content knowledge, and critically reviewed procedures preceded the solution seeking processes, students attended to key concepts and principles and learned as intended. During the process, students employed questioning, explaining, reasoning, etc. under the style code of reacting (RA), which promoted the development of the higher levels of cognitive abilities of analyzing, applying, evaluating, etc. as shown in Table II. However, when students responded to a posed problem with routines for seeking a predetermined solution, they discounted the underlying concepts and key issues in the domain knowledge. Their group talks stressed facts and unreviewed procedures, and typically used a simple statement for agreement or disagreement coded as "responding (RS)" in discourse style analysis. In situations such as these, the posed problem failed to engage intended learning.

Case I: Problems that fail to engage learning



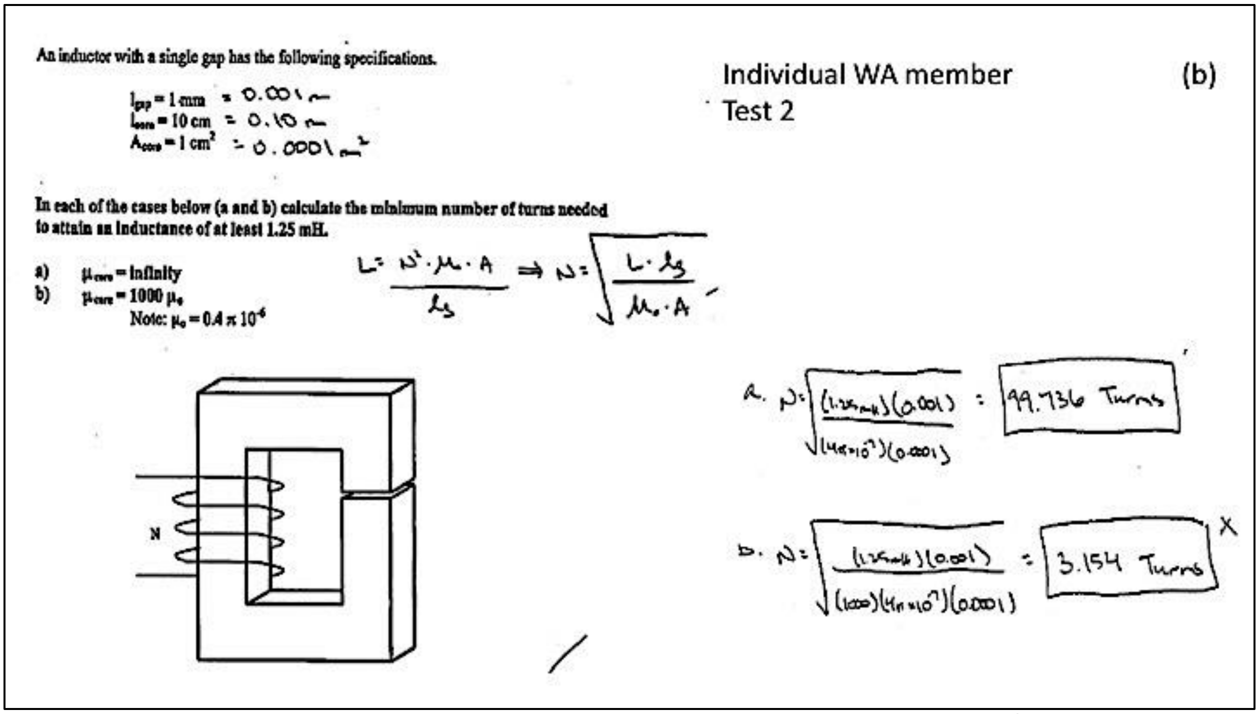


Fig. 1. (a): Problem for the group exercise; (b) Problem in the second midterm.[2]

In this study, features of problems that fail to engage students in learning as intended were revealed. Fig. 1(a) shows one such problem with perceived “normal and standard” representations that drive students to rush through problem-solving processes habitually without being watchful of important concepts and principles in the domain knowledge. Detailed analyses of two group discussions, Groups WA and FL, while working on the problem disclosed such behaviors. Table III shows the representative talks from one group, Group FL. Line numbers in the table indicate an uninterrupted individual’s talk. Types of content and styles of utterances for an uninterrupted individual’s talk are identified. Both group talks were brief (N=20 for FL, and 30 for WA) and were centered on factual knowledge and uncritically reviewed procedural knowledge. Conversations among group members were about “how”, but not “why”. During the process, students were not challenged to reveal either their misconception or ambiguous interpretations of content knowledge. Students’ superficial understanding was uncovered when they were asked to solve a similar problem of the same topic. More than 65% of the class (about the same for these two groups of 8 students) failed to solve the problem, shown in Fig. 1(b) independently in the test (T2) right after the group exercise. Content problematizing in this case was unsuccessful in involving students in grappling with and reflecting on key issues of domain knowledge. It encouraged uninspired rote learning and failed to help student to construct a knowledge base to support problem solving, leading to substantial mismatches between teaching and learning objectives.

Table III. Group Discussion Discourse s for Case I

Line No.	***Verbal Discourse (Group FL, N=20)***	***Content Code***	***Style Code***
1	*P2: Cut this into half? Add two?*	*P*	*SO*
2	*P1" Yeah---Since this has different permeability, I have to find both----after that we can find---*	*C*	*RA*
3	*P2: F mu over L*	*P*	*RA*
4	*P2: I have F , not an I?*	*F*	*SO*
5	*P1: Yeah.*	*F*	*RS*
6	*P2: Alright, then?*	*P*	*SO*
7	*P1:----Mumbling through equations, for this we can get---*	*P*	*RS*
8	*P2: Ern ---did you get this?*	*F*	*SO*
9	*P1: No, I did not finish it.--*	*F*	*RS*
10	*P2: Yeah.*	*F*	*RS*
11	*P1: You can do this*	*F*	*RS*
12	*P2: Oh.*	*F*	*RS*
13	*Most time worked*	*F/P*	*RS*
14	*P2: OK. 377 micro--*	*P*	*RS*
15	*P1: What's the unit?*	*P*	*SO*
16	*P2: Alright that's it---questions I guess.*	*F/M*	*RL*
17	*P3: The first part. The area of the cord and the gap. They are divided by 2 for the ratio.*	*F/P*	*RS*
18	*P2: No, we divided the area by two to do with the two gaps.*	*F/C*	*RA*
19	*P3: OK.*	*F/C*	*RS*
20	*P2: If it is one happy gap, we just took that. Then added that. That's what we did.*	*F/P*	*RA*

Case II: Problems that successfully engage learning as intended

This study shows how students struggled with unfamiliar representations of the posed problem and were challenged to understand the problem before searching for solutions. Fig. 2 displays the problem for the task. Discussions from the same two groups (groups FL and WA) for the first study were analyzed. Excerpts of one group discussion, Group FL, are shown in Table IV. Students were confronted with their learning habits of hurrying through the process of selecting an equation. They engaged in lengthy and in-depth discussions to create problem representations in understanding the problem goal. They expressed their opinions openly, made inquiries, provided explanations to peers’ questions, and critically reviewed others’ opinions. Despite struggles at times with difficult concepts, these experiences promoted thorough knowledge acquisition and inquiry. During the process, students were attentive in identifying major concepts, and searched for solutions only after they first critically reviewed underlying principles and appropriate procedures. The engagement yielded positive learning outcomes through reflective and collective work that settles disagreement. Detailed discourse analyses show that talks for both groups were centered on conceptual and procedural knowledge for deep learning.

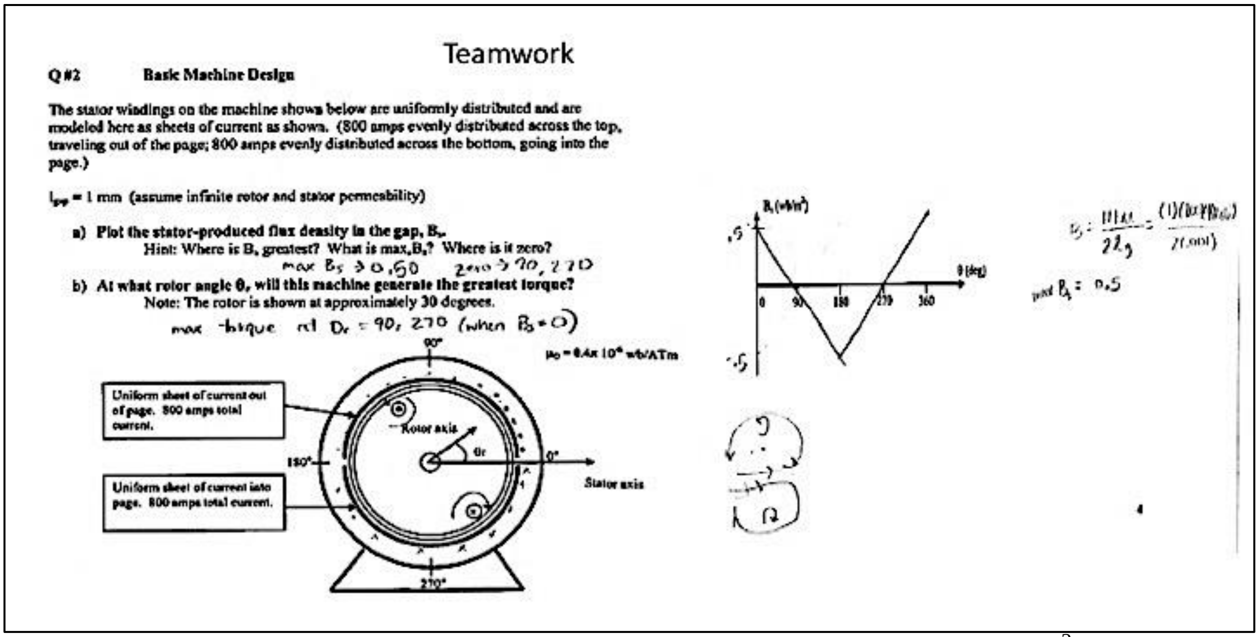


Fig. 2 Problem for the team exercise that engaged lengthy group discussions[2]

Table IV. Excerpts of Group Discussion Discourse for Case II

Line No.	***Verbal Discourse (Group FL, n=77)***	***Content Code***	***Style Code***
1	*P1:this is the equation what we are supposed to use, but I am confused about is that little f, the unit says amps---*	*F*	*IN*
2	*P2:I think it is supposed to be f--*	*F*	*RS*
3	*P1:I think it should be s(?), because it is negative*	*F*	*RS*

13	*P1: What theta R is this?*	*F/C*	*SO*
14	*P2: I would consider H, so B*	*F/C*	*RA*
15	*P1: I don't know the direction*	*F/C*	*SO*
16	*P2: Me too. I think the flux in going this way. But, it (current) is uniform everywhere. I don't know what this means. Is this the only gap?*	*C*	*RA/SO*
17	*P1:This is one gap, this one gap ---two gaps*	*C*	*RA*
18	*P2: I think this Lg.*	*F/C*	*RA*
19	*P1: What? Yeah. This is.*	*C*	*RS*
20	*P2: So, this is degree, This is zero degree, and---this 180 degree. So essentially, zero and 180 degree have the flux. Like, plus one and minus one or something.*	*C*	*RA*

35	*P3: and if you---I don't know*	*C/M*	*RL*
36	*P2: Now, what?*	*C*	*SO*
37	*P3: What made you decide the width of these, how wide is it going to be?*	*C*	*RA/SO*
38	*P2: Well, it would be the width of this. So, it's like 90 degrees or something, a dolphin (refers to the shape of stator or motor) from here to here, but it will be from here and there. This one likes a from here to there dolphin. This one like is pretty an impulse.*	*F/C*	*RA*
39	*P2: I am approaching this way.*	*M*	*RL*
40	*P3: How do you pay attention to these gaps?*	*C*	*SO*
41	*P1: think--They usually have them--like the first one. They had like this*	*C*	*RA*
42	*P3:it's the gap, right?*	*C*	*SO*
43	*P2: They specified that from here to here was 90, here to here was 90. That means it's squared up. So, this is like things really happen. The other one is like this ---then*	*F/C*	*RA*

	it's initialized this way. So it's xx like a circle.		
44	*P2: Do you remember the "camera" thing?*	*F*	*SO*
45	*P3: The gasp was 2 milliseconds?*	*C/F*	*SO*
46	*P2: Yeah.*	*C/F*	*RS*
47	*P3: So you were saying everywhere ---here will be 1 millisecond?*	*C*	*SO*
48	*P2: Yeah. It's squared up. So each of these will be one millisecond*	*C*	*RA*
49	*P1: Do you have ---*	*C*	*SO*
50	*P4: Not much. I was hoping you guys--*	*C*	*RL/SO*
51	*P3: Did he tell us to add it or if he forgot to tell us to add it?*	*F*	*SO*
52	*P2: No, It tells you. It says the current is coming out and current is coming in. So, we drew it.*	*F*	*RA*
53	*P3: OK*	*F*	*RS*
54	*P3:.B would be same value up to? This zero right? OK. Then it will be 90 then the same value till 180 again. I would think this will be bigger, for this small area?*	*C*	*SO*
55	*P2: This thing--- Did you see the first problem, if this is familiar at all. This is the only open part for the flux, this little area.--that's why we had the impulse.*	*C*	*RA*
56	*P3: Oh---*	*C*	*RS*
57	*P2: That's the way we interpreted it.*	*C*	*RA*
58	*P3:That would change the value of B though--*	*C*	*RA*
59	*P2: That would decrease B, when B would work because is zero*	*C*	*RA*
60	*P3: So you are thinking of one gap? Air gap?*	*C*	*SO*
61	*P2: No. That's not your air gap,*	*C*	*RA*
62	*P3: What's that?*	*C*	*RA*
63	*P2: That's the flux gap, where flux gets through.*	*C*	*RA*
64	*P3: Flux gap?*	*C*	*RA*

74	*P3: Not start here?*	*C*	*RA*
75	*P2: No. This is theta R. At theta R they are here and here. When you bring it back, the zero degrees starts here. They only got here at 90 degree.*	*C*	*RA*
76	*P3: Oh Yeah, that's right. Alright.*	*C*	*RS*
77	*P2: Then is positive when is dot- and x-the dot is towards b, and negative is opposite*	*C*	*RA*

(a)

Knowledge Type	WA-1-T2	FL-1-T2	WA-2-T2	FL-2-T2
Factual	43.3%	50%	25%	25.9%
Conceptual	6.7%	11.5%	62.8%	69.4%
Procedural	46.7%	34.6%	11.5%	0
Metacogitve	3.3%	3.8%	1%	4.7%

(b)

Utterance Style	WA-1-T2	FL-1-T2	WA-2-T2	FL-2-T2
Responding (RS)	40.7%	47.6%	28.6%	18.5%
Reacting (RA)	40.7%	19%	61.3%	49.3%
Reflecting (RL)	11.1%	4.8%	2.5%	6.2%
Soliciting (SO)	3.7%	23.8%	6.7%	24.7%
Initiating (IN)	3.8%	4.8%	1%	1.3%

Fig. 3. Comparison of group discussion (groups WA and FL) content and style while working on problems 1 and 2 shown in Fig. 1(a) and Fig. 2, respectively. (a) Content analysis; (b) Utterance style analysis.

Fig. 3 summarizes group discourse analyses for the first two case studies. It compares the discussion content and utterance style for two different types of problems. One is overtly well-structured (see Fig. 1(a)) and elicited talks predominately on factual knowledge (WA-43.3%, FL-50%), whereas the other is an adjusted approach with multiple representations (see Fig. 2) that engaged talks on conceptual knowledge (WA-62.8%, FL-69.4%). Students used the style of reacting (RA) overwhelmingly for problem 2, instead of responding to simply agree or disagree without explanations and reasoning. (WA: RA-61.3%, RS-28.6%; FL: RA-49.3%, RS-18.5%). It is evident that ways of content problematizing can either positively influence learning outcomes or negatively hinder learning.

Case III: Resources for discourse development that supports content problematizing

(a)

Q #1 **DC Machines**

A DC machine is driving a load characterized by $T_L = 10 + 0.1\,\omega$ Nm = Tem
The machine is fed by a 50 V source and has the following machine parameters.

Machine parameters: Va = 50
Ra = 0.6 Ω
$k_T = 0.5$
$k_E = 0.5$

Calculate the speed of this machine.

(b)

Content (Knowledge Type)	OR-1-T3 (N=84)	MN-1-T3 (N=20)
Factual	3.5%	34.3%
Conceptual	19.5%	9.3%
Procedural	58.4%	31.3%
Metacognitive	18.6%	25%

(c)

Utterance Style	OR-1-T3 (N=84)	MN-1-T3 (N=20)
Responding (RS)	35.2%	63.1%
Reacting (RA)	40.9%	15.8%
Reflecting (RL)	12.5%	5.3%
Soliciting (SO)	9.1%	10.5%
Initiating (IN)	2.3%	5.3%

Figure 4. (a) Problem for the activity; (b) Group discourse content: (c) Group utterance style.

In this study, we used the data from a previous study to uncover uneven engagement and response to problematized content.[3] Content problematizing in this situation was designed to make students attentive to the concept of "steady state" in DC machines. The problem, shown in Fig. 4(a) displayed neither all required elements explicitly nor a preferred solution process. For example, torque is expressed as a function of angular frequency ω, and the assumption of "steady state" is expected to come from students. Detailed analyses of two group discourses, Group OR and MN, show that it was successful in helping one group, Group OR learn as intended, yet it failed to do the same for Group MN.

As displayed in Figs. 4(b) and (c), Group OR engaged in lengthy discussions (N=84), articulated contextual constraints, and resolved disagreement among the four members. For Group OR, factual knowledge is only at 4% of discussion content, and RA is at 41% and RS 35% of utterance style. In contrast, Group MN had a brief discussion (N=20) on surface features (34.3% factual knowledge vs 9.3% conceptual knowledge) and failed to recognize and resolve different opinions. Group MN did not act to the level as intended, and missed the learning opportunity. (Group MN in style: RS-63.1%; RA-15.8%). What was overlooked for this problem, even though it was designed by a balanced approach, was the resource required in facilitating the development of group discourse. Because students bring different prior knowledge, beliefs, and experiences into their group discussions, they need to establish a common ground for effective group work. To do so, group members must first understand that it is normal to have different opinions within the group. They should learn to appreciate and be able to resolve any existing disagreement before they advance their learning.

Discussion

Group discussion discourse analysis shows the content of group discussion and ways in which students respond or react to the problems posed by the instructor. These talks reveal if and how students learn as intended during the process. Quantifying coded verbal utterances in both content and style provides indicators of the development for both content knowledge and cognitive ability and provides insight into instructions for engaged learning in flipped classrooms. In general, when students are challenged by the cognitive aspects of the problem and engaged in dialogic inquiries, they use the time provided to create problem representations, define the problem space, confront and repair misconceptions, and to learn how to produce conceptual and solution models reflectively and collectively.

I. Features of content problematizing that fail to engage intended learning are typically structured with (i) presenting all elements to learners, (ii) possessing one correct solution, (iii) preferring a predictable solution process, and (iv) requiring application of regulated principles and rules.[12] As shown in Case I, when students are not challenged or required to look deep into key issues of domain knowledge, gaps between teaching and learning objectives emerge. Mismatches were particularly noticeable when undistinguished problems that are overtly well-structured do not engage students in productive group discussions. These problems, with a predictable solution path, fail to draw students' attention to the required types of knowledge acquisition. All necessary information is explicitly included and no reasoning and explanation is required. In these situations, students concentrated on superficial features and were anxious for a predefined solution through recalling learned equations and other memorized facts and procedures. As soon as a solution appeared, learning departed from the intended tracks of creating and relating the base knowledge to key discipline issues. The ensuing gaps hindered conceptual learning and conceptual growth as shown in Case I.

II. Results from Case II show that design and delivery of content problematizing should focus on articulating problem spaces for the development of higher levels of cognitive abilities. Content problematizing with one or more representations was able to engage students in learning as intended, because it required students to attend to underlying concepts before attempting the solution processes. It thus strengthened their conceptual understanding and helped them learn better. In contrast to the problem shown in Fig. 1, the problem shown in Fig. 2 purposefully utilized an approach for content problematizing, which required students to encounter their unfamiliar representations and to translate correctly from one mode to another. Even though the problem had a preferred solution, it did not explicitly include all the needed elements, and allowed divergent solution processes for convergent solutions. In this way, the enhanced cognitive aspect/flexibility with a variety of representational modes challenged students to define, interpret, and model problems and solutions. Research findings have long supported the necessity of representational fluencies across various engineering practices and shown evidence that an important element of design and problem solving in engineering involves shifting back and forth among a variety of relevant representations.[16, 19,20]. Incorporating the Lesh Translational Model in design considerations has prevented students from rushing through solution processes without being thoughtful of subject-matter issues that are the goal of instructions. The study of Case II illustrates techniques of problematizing content knowledge in engaging learning as intended.

III. Results from Case III show that learning disparities arose because of an ineffective group discussion. They highlight social context for content problematizing. Disparities in student responses to posed problems and artifacts, even with balanced approaches were observed. Factors for these differences can be various: students' prior knowledge, their beliefs, personal experiences, group learning dynamics, etc. Because these problems are rich in context, they demand deep understanding of content knowledge both conceptually and epistemologically. Resources that facilitate group discourse development and that provide base knowledge structure are required and should be an important strategy in instruction delivery given the reliance of group discussions for problem solving. A few prompts to ask each group member to pay attention to peers' positions and understanding were necessary. For example, questions such as "are you sure?", or, "how do you know that your friends and you are talking about the same thing?", or, "how do you know that the group has resolved the difference?", etc. Seemingly trivial, these prompts should in principle be included in each learning activity, involving students in making reflective judgments for every task, ensuring group discourse that reaches intended and consistent learning. They will help students communicate problem goals, construct base knowledge, and select the best solution model based on reasoning and conceptual understanding while overcoming learning disparities.

Summary

Flipping classrooms offers an incredible opportunity for creating an authentic learning environment, whereas implementation of problem-centered learning plays a key role in maximizing the potential of this innovative instruction method. Supporting students to learn from difficult experiences is both beneficial and challenging. While it is expected to better prepare students for future learning and for working in real-world situations, it continues to challenge the effectiveness of instructional design and implementation. Problematizing content requires students to uncover unfamiliar disciplinary ideas, apply them to actions for the task at hand, and make their understanding public and explicit. In this way, the artifact students interact with and create of their interpretations becomes a vehicle for negotiation of understanding about the disciplinary ideas and their applications.[12] This study examines instructional design for problematizing content and concludes that with necessary and accessible resources, balanced approaches that are adjustable between the so-called well-structured and ill-structured problems show promise in aligning teaching and learning objectives. It also shows that fostering collaborative learning should be integral to the content problematizing, which eases uneven learning outcomes.

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