Classroom Discourse Development for "Flipping Classrooms": Theoretical Concepts, Practices, and Joint Efforts From Engineering Students and Instructors

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***Abstract*—This study applies discourse analysis using revised taxonomy to evaluate the effectiveness of the instructional model and assess students' learning gains simultaneously. It examines conditions for the development of classroom discourse that facilitates learning in "flipped classrooms".**

Keywords—instructional model; flipping/flipped classrooms; classroom discourse; joint efforts.

I. INTRODUCTION

"Flipping classrooms" is an emerging instructional approach that replaces traditional lectures with other learning activities during in-classroom periods [1-6]. Recently, it has drawn increasing support because it has changed classroom dynamics enhancing teaching and learning. However, it has not been universally embraced with concerns regarding the quality of learning in flipped classrooms. Skeptics are wary of the inverted format believing that it no longer offers traditional schooling in which professors are the sole authoritative figures to transmit knowledge. Just as with any new instructional models that are intended to improve engineering education, the effectiveness of non-traditional "flipped classrooms" needs to be tested. Research that measures how teaching practices in "flipped classrooms" influence students' learning is required. Evidence obtained from these studies will inform engineering instructors and institutions as to what works, what does not work, and why it does or does not work.

This study investigates two research questions: (1) How does the implemented Four-Practice Instructional Model in "flipping classrooms" influence the classroom discourse development? (2) In what ways does the development of classroom discourse impact student learning? The rationale of the study is to further our understanding of how engineering students learn through dialogic discussions and inquiries in classroom so that we can design better instructional approaches that maximize the teaching and learning potentials in "flipped classrooms". This study was designed to help show that our newly designed instructional model has enabled active learning through: (1) a learning community that includes both the instructor and students, and (2) classroom interactions centered on the development of classroom discourse [7] [8].

Our research methodology comes out of the theories of learning taxonomy and focuses on communicative teaching and learning [9]. Through this method, we conceptualized learning supported by the Four-Practice Instructional Model in "flipped classrooms" to generate and direct classroom discourse and turned it into pedagogical tools. We applied discourse analysis using revised taxonomy to evaluate the effectiveness of the instructional model and assess students' learning gains simultaneously.

The main strength of the Four-Practice model is the emphasis on the joint effort of a learning community that includes both students and instructors [7] [8]. We have found that the instructional model has helped redefine the role of instructors in non-traditional teaching, and that flipping lectures has helped make teaching and learning a mutual responsible task for both students and instructors. The role of Vygotsky's theory of the zone of proximal development (ZPD) is significant in the design and the development of the instructional model that has shaped the agenda of classroom discourse [10] [11]. It helps to understand that individuals are able to learn certain types of knowledge and skills better only with assistance, while they cannot learn, or can only learn with difficulties when they study alone. One of the two expositions of the ZPD in Vygotsky's published work arose from the immediate concern of the role of instruction in the development of scientific concepts [11]. While developing and implementing the new instructional model for "flipped

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classrooms", we focused on the critical role the instructor played in establishing classroom discourse to facilitate such teaching and learning [12] [13]. Descriptions of the Four-Practice Model and refined roles of instructors are shown in Table I. Each practice of the model highlights principles for active learning, shown with bold fonts [7]. Instructional interventions are characterized by a two dimensional model for classroom discourse as shown in Table II [7]. The current study sought to evaluate if the implemented instructional model for "flipping lectures" created conditions for collaborative discourse that focused on inquiries and explanations. By having problematized course content that allowed students to raise questions and respond to each other when they were put together in small groups to solve problems and learn course content, a relationship between student utterances and knowledge construct and the role that classroom discourse played in the process was examined.

TABLE I. FOUR-PRACTICE MODEL

Four-Practice Model	***Description***
Anticipating	**Problematizing content** • Anticipate students' learning demands
Monitoring	**Giving students authority over their study** • Probe students' responses and engage in conversations with students • Keep group discussions on track
Connecting & Contrasting	**Holding students responsible to others and to norms of discipline** • Elicit questions and encourage dialogic inquiries • Contrast students' views to discipline norms
Contextualized Lecturing	**Providing relevant resources** • Lecture based on students' responses

TABLE II. CHARACTERISTICS OF CLASSROOM COMMUNICATIONS IN THE INSTRUTIONAL MODEL

	Interactive	***Non-interactive***
Dialogic	Monitoring Connecting & Contrasting	
Authoritative	Contextualized Lecturing	Anticipating

II. BACKGROUND INFORMATION

A. *Theoretical Concept and Practices*

Decades of research on discourse has supported the fundamental role of classroom talks in education. As Halliday puts it, "language is the essential condition of knowing, the process by which experience becomes knowledge" [14]. Much research, for example the study by Chin and Obsborne, discusses the potential of students' "utterances" as an epistemic probe and a heuristic for constructing knowledge collaboratively in classrooms. Other studies indicate that the nature and the quality of the classroom talks are central to improving learning [15]. From Vygotsky's perspectives of ZPD, the emphasis on mutuality of the individual and the sociocultural environment preserves the essence of classroom discourse in learning [10]. Problematizing course content and small group problem solving utilized in the Four-Practice Model are proven to be effective in engaging students in active learning, particularly in learning cognitively demanding content and skills. By analyzing students' utterances in group discussions, we have found group discussions have helped students change their learning beliefs and habits significantly [8]. The current study emphasized that the development of classroom discourse is a mutually constituting process that includes the three coexisting planes of personal, interpersonal, and community [16]. See Figure 1. It assessed conditions that facilitated the development of classroom discourse and identified factors that enhanced discourse to improve learning. It examined the nature of students' utterances in group discussions, which informed us as to how they know what they know and how they use dialogical discussions to support their learning in the educational context of the new instructional model for flipping classrooms.

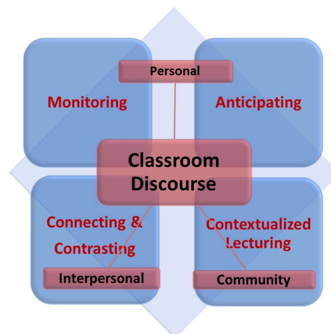

Fig. 1. Classroom discourse process supported by the Four-Practice Model

B. *Research Approaches and Setting*

Design-based-methods applied in this study continued to allow us to build a close partnership between the course instructor and education researchers [17] [18]. The team met regularly every week to share classroom observations and make timely changes in instructions and data collections. The approach enabled feedback to further improve teaching, learning, and research through iterative circles [7] [8].

The research design comes out of the approach of natural inquiry that allowed us to focus on two research questions [19]. Data collection and analyses were guided by the theoretical concept and practices for this study [7] [8] [16]. The study's setting was in the Electric Drives course in the Electrical and Computer Engineering Department at the University of Minnesota [20]. From 2012-2014, three groups totaling 250 students participated in this study.

C. *Data Collection*

(1) Students' verbal discourse, while working within a small group on problems posed by the instructor was observed by researchers and audio recorded. The recorded voice data were transcribed, coded, and analyzed by the developed scheme. The coded verbal discourse was quantified to facilitate data analyses.

- Spring 2013: Five out of 10 groups in the class were selected for audio recording based on their relatively consistent class attendance. Recorded talks of Group O for one problem and Group T for a different problem are shown in this report.

- Spring 2014: Students were divided into 18 groups with 3-5 students in each group. Audio recording took place during the first day of the class. Taping during the first six weeks was limited due to a shortage of recording devices. All group discussions were recorded once each week after that.

(2) Students' team worksheets and exam papers were collected and analyzed. Some were analyzed in conjunction with verbal data.

D. Data Analyses

(1) Coding schemes for verbal data

The framework of coding schemes for verbal data analyses is based on the revised Taxonomy of Educational Objectives [9]. Because the taxonomy of education objectives is a framework for classifying statements of what we expect or intend students to learn as a result of instruction, it provides us with a means to evaluate educational objectives and activities of our instructional model. We adopted the knowledge dimension to assess whether students increased their mastery of conceptual and procedural knowledge to meet the course objectives. See Table III. We adapted a coding scheme in the cognitive domain to analyze student utterances and characterize student-to-student talks. Although not shown here, structural components of verbal discourse and underlying cognitive processes in small group problem solving were studied to reveal the development of cognitive abilities [8].

TABLE III. KNOWLEDGE DIMENSION OF CODING SCHEME

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 fist 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…"*

(2) Relationship between verbal discourse and written work

Team problem solving worksheets and exam papers were analyzed to assess the authenticity and effectiveness of the classroom discourse. It helped us to understand if and how group talks had influenced students' learning of content knowledge.

III. RESULTS AND FINDINGS

A. Verbal Data Collected During Group Problem Soving

Fig. 2 displays group talks. Fig. 2(a) shows the percentage of the talking characterized by the knowledge dimension for Group O, and Fig. 2(b) shows the same for Group T [8]. Fig. 3 displays the group talk progression within a session for the two groups. The data for Group T (red dots) are displayed with a slight offset. Excerpts of students' verbal discourse for Group O are shown in Table IV. The two problems for the two groups are shown in (a) and (b) of Fig. 4, respectively. We observed different patterns of these two group talks and gathered more information to understand how and why it happened in spring 2014.

TABLE IV. EXCERPTS OF GROUP DISCUSSION VERBAL DATA

Line No.	Verbal discourse (Group O, n=5)	Code
1	*P2: I_{ms} is going to be B_{MS}OG over mu naught S, I think.*	*F*
2	P4: Say it again.	*F*
3	P2: (Repeat) I_{ms} is going to be B_{MS}OG over mu naught S (Repeats). The only thing I'm not sure about is the M_S, but I think that's right. We don't have any other currents.	*F*
4	P3: Are a couple of these including 90 degrees apart, or do you have to…?	*F/C*
5	P2: So, the currents are always parallel with the flux and then currents induced by volts are 90 degrees ahead. So the I_S will be pointing straight up and the I_{MS} would be pointing straight down. I know that much.	*F/C*
6	P4: Wait, the I_S will be…?	*F/C*
7	P2: The I_S will be straight up and the I_{MS} will be straight down. In line with the B_{MS} flux.	*C*
8	P4: Because the I_S is behind the B_{MS}.	*C*
9	P3: The I_S is….?	*C*
10	P4: Wait, hold on. I keep getting confused with the directions here.	*C*
11	P2: I_S is induced by the B_S's, isn't it? Hm, I_{MS} in line with I_S then?	*C*
12	P4: That doesn't make sense.	*C*
13	P3: I don't think that those two are in phase.	*C*

47	P3: How do you get the magnitude of S?	*C*
48	P4: You add them. You add $I_{R'}$ and I_{MS}. What's the value of B?	*P*
49	P2: It's .3 webers/meter^2	*P*
50	P4: Times L which is .001/forty/forty-five. It's 2.	*P*

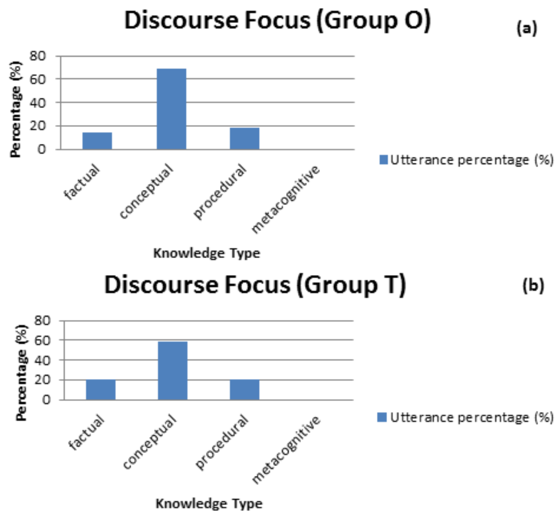

Fig. 2. Utterance counts in group discussions displayed along the knowledge type dimension

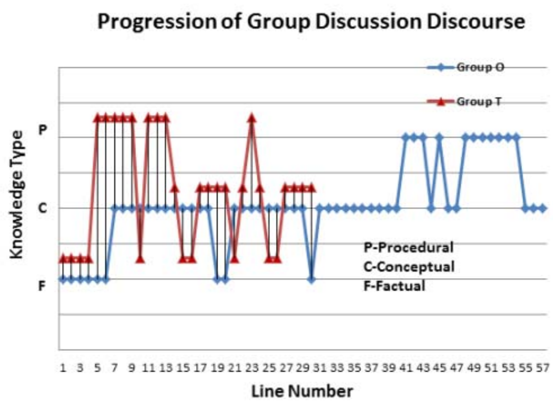

Fig. 3. Utterance progression in group discussions along the knowledge type dimension (shown with an offset)

Fig. 5 displays group discussion discourse during a review session before the second midterm exam of spring 2014. Students were asked to work in teams on two mock test problems. Group talks of 7 teams were audio recorded and two group talks (Groups WA and FL) were randomly selected and are shown here. Fig. 5(a) displays talks from Groups WA and FL working on problem 1, and Fig. 5(b) for group talks on problem 2. The amount of talking characterized by the knowledge dimension of the revised taxonomy for these two groups is displayed. Fig. 6 displays the group talk progression within a session for these two groups. Fig. 6(a) for problem 1 and 6(b) for problem 2. Both teams worked with the same two problems shown in Figures 7 (Problem 1) and 8 (Problem 2), respectively. One of the data sets (red dots) is shown with a slight offset. Group WA correctly solved both problems, while Group FL successfully completed one of the two. After group discussions, the instructor spent 15 minutes answering questions and showing solutions of both problems upon students' request. Students took the midterm exam right after the group activity. Tables V displays the transcribed and coded verbal excerpts of group discussions (Group FL, Problem 2) shown in Fig. 5(b).

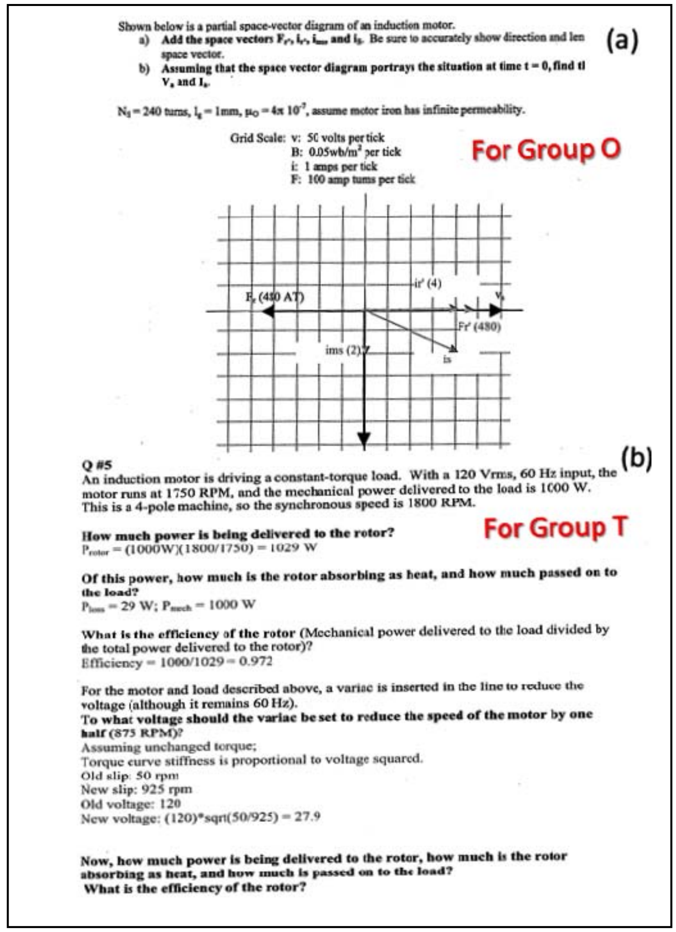

Fig. 4. Problems for group discussion. (a) Group O; (b) Group T.

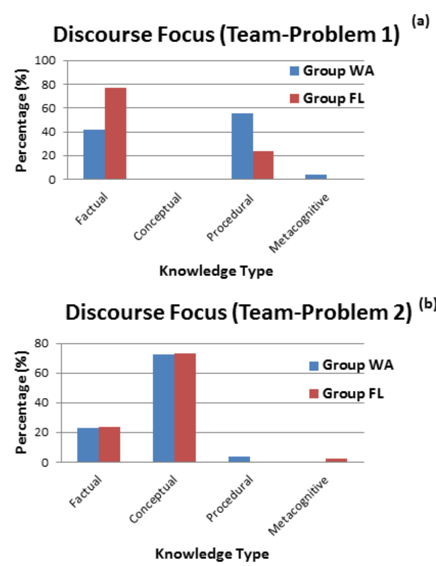

Fig. 5. Utterance counts in group discussions along the knowledge type dimension

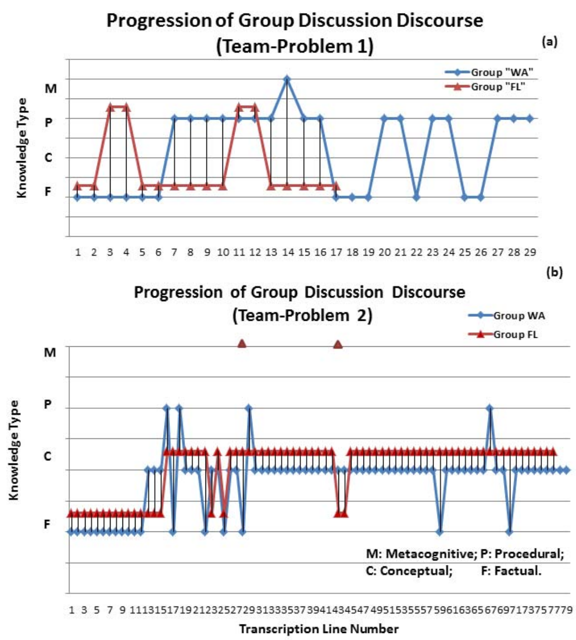

Fig. 6. Utterance progression in group discussions along the knowledge type dimension within a session

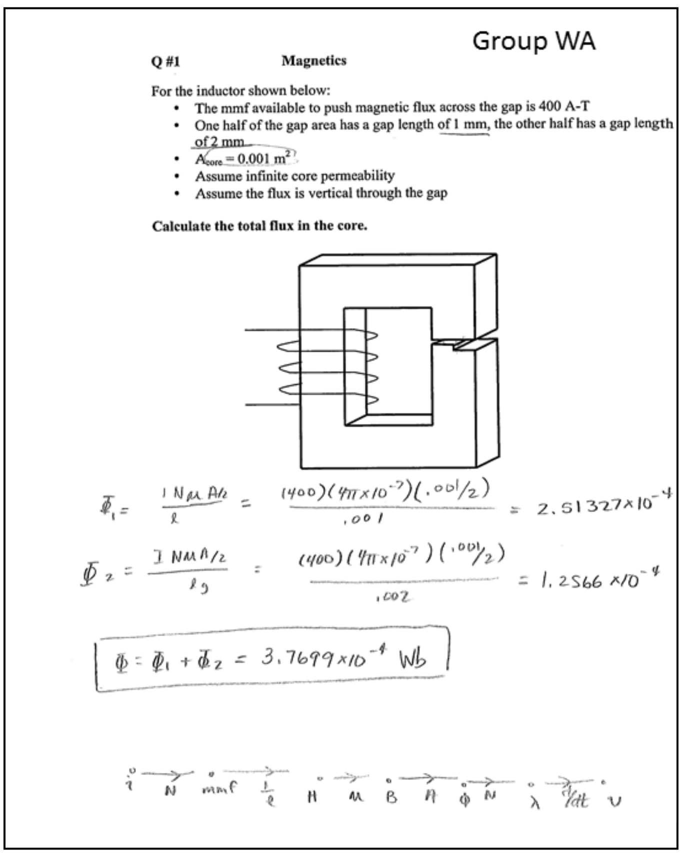

Fig. 7. Team (Group WA) written work of Problem 1.

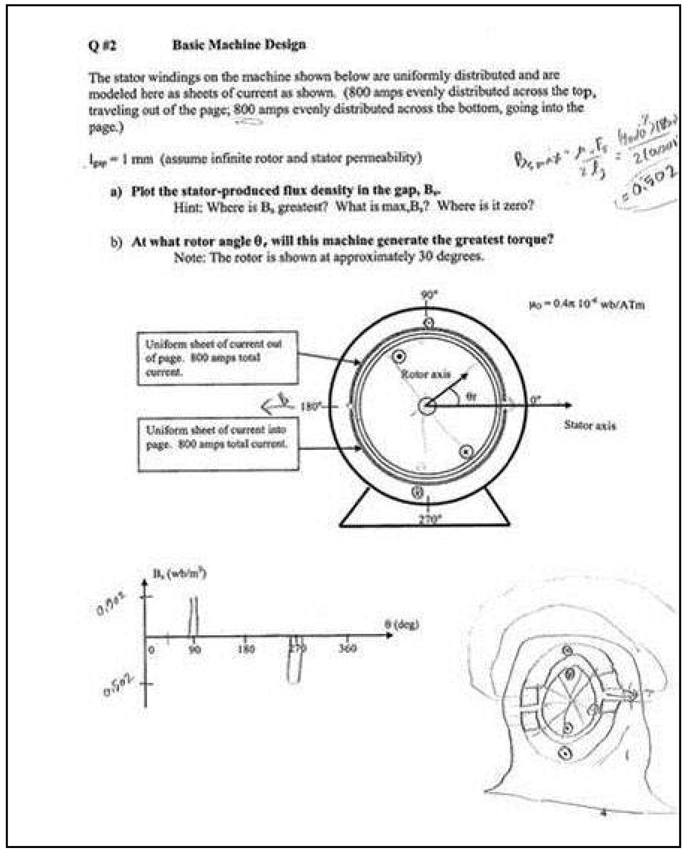

Fig. 8. Team (Group FL) written work of Problem 2

B. Verbal Discourse, Written Work, and Posed Problems

Group talks shown in Fig. 2 and Fig. 5, and selected excerpts of these talks shown in Tables IV and V tell us how students know what they know in different ways. Through discussions, students worked collaboratively to solve problems posed by the instructor. Their talks focused mainly on conceptual and procedural knowledge, a discourse development that is expected to achieve over a certain period [8]. In the process of problem solving, students learned new materials by constructing their knowledge with their peers instead of passively receiving instructions from the instructor. They asked questions, provided explanations, and explored different approaches to seek solutions. However, the length of discussions responding to different problems differed. This disparity was observed in the data shown in Figures 2(a) and 2(b), and was more evident for group talks shown in Figures 5(a) and (b). While Figures 2(a) and 2(b) display group talks for two different groups working on two different problems, Fig. 5 shows group talks of two groups working on the same problem. In addition, Figures 5(a) and (b) compare verbal discourse for the same two groups for two different problems. It reveals possible causes giving rise to the scope and the depth of students' discussions. Some types of questions clearly engage students in discussions with depth while others fail to do so. For example, problem 1 shown in Fig. 7 is a typical textbook-like question that asks for numerical solutions. Data shown in Fig. 5(a) illustrate students' responses to the problem. They picked an equation and then plugged numbers in to get a solution. In this case, group talks quickly came to an end even before they got a chance to expose their misconceptions, if they had any. Problems like this unintentionally encourage long-standing poor learning habits in problem solving: picking up equations without conceptual understanding [8] [21]. In contrast, problems that are not as "straightforward", for example asking for graphical solutions, stimulate interesting and rich dialogues that include utterances of lengthy questioning, explaining, exploring, and critical reviewing. When comparing the group work on the two problems framed differently, although both for free responses, it is clear that types of posed problems (not content) can be critical in the process of classroom discourse development. Seeking solutions for these two types of problems generated group talks that were very dissimilar in both the breadth and depth of their discourse. They affected students' learning significantly.

TABLE V. EXCERPTS OF GROUP DISCUSSION: TEAM-PROBLEM 2

Line No.	Verbal discourse (Group FL, n=4)	Code
37	P3: What made you decide the width of these, how wide is it going to be?	*C*
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 is like --- from here to there, a dolphin. This one like,--- is pretty much an impulse.	*F/C*
39	P2: I am approaching this way---	*C*
40	P3: How do you pay attention to these gaps?	*C*
41	PI: I think. ---They usually have them---like the first one. They had like this.	*C*
42	P3: It's the gap, right?	*C*
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 (that) really happens. The other one is like this ---then it's initialized this way. So, it's like a circle.	*F*
44	P2: Do you remember the "camera" thing?	*C*
45	P3: The gasp was 2 milliseconds?	*C*
46	P2: Yeah.	*F/C*
47	P3: So you were saying everywhere ---here will be 1 millisecond?	*C*
48	P2: Yeah. It's squared up. So each of these will be one millisecond	*C*
60	P3: So you are thinking of one gap? Air gap?	*C*
61	P2: No. That's not your air gap,	*C*
63	P3: What's that?	*C*
64	P2: That's the flux gap, where flux gets through.	*C*
64	P3: Flux gap?	*C*
65	P2: I don't know how to---this is the first problem that they had. So the flux in only going through here. There is no flux here. Not here. But, in this one, this is down here. Does that make more sense to you now? Like why we chose that?	*C*
66	P3: So there is one here and one here?	*C*
67	P2: Yeah, the angle is pretty much impulse, like zero plus or minus one. Something like that.	*C*
68	P3: So you were saying this area here prevents flux?	*C*
69	P2: It's---you will not get B from that.	*C*
70	P3: Really?	*C*
71	P2: All the flux lines you cross--- it's only right here. It's here not here. So it's not cutting lines like this	*C*
72	P3: Why don't you have an impulse at zero?	*C*
73	P2: Because,--- it only starts here and here.	*C*
74	P3: Not start here?	*C*
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*
76	P3: Oh Yeah, that's right. Alright.	*C*
77	P2: Then it is positive when is dot- and "eks" (x) ---the dot is towards B, and negative is opposite	*C*

C. From Group Talk to Written Work

The written group works shown in Figures 7 and 8 correspond to verbal discourse shown in Figures 5(a) and (b), respectively. For problem 1, both groups skipped discussions concerning conceptual knowledge because the problem only asked for a numerical solution. Students had no difficulties finding the right equation to calculate the flux. Group talks were brief, jumping from factual to procedural. For a "fairly straightforward" problem, there was no need for mentioning underlying concepts at all. The written work for both teams was brief and seemed to show a good mastery of basics of magnetics and inductance. In contrast, both groups spent a substantially longer time (4-5 times longer) working on the second problem. This problem asked students to plot the air gap flux density produced by the given stator current winding configuration. Solving the problem required deep conceptual understanding. Students were challenged to think critically, and focused on conceptual discussions (more than 50%) most of the time. All team members engaged in these extensive discussions. They voiced their views of conceptual understanding as well as misconception. At the same time, they reviewed their peer's opinions and provided feedback and explanations. At the end of the discussion, it was clear students were encountering a challenging question that demanded help from the instructor. The group talks showed students' own reflective utterances such as "I don't know---" and " I did this in the past, but---". Both teams' written work showed various degrees of understanding, consistent with what they discussed in the group discussion.

To understand how students translate their teamwork into personal understanding and to see if they internalize learning, we took a close look at their individual work. The two problems in the second midterm exam covered similar topics: magnetics and inductance, and basic machines. As expected, some students struggled with problem 2 that pertains to basic machines, a challenging topic indicated by their group talks. Their work on problem 2 showed their improved conceptual understanding (not shown due to the limited space). However, we found that more than half of the class did not score well for the magnetic and inductance problem, Problem 1. It seems to be a one-step question. Yet, it requires conceptual understanding to apply the equation. Students' work revealed misconceptions about magnetic fields, flux density, and fundamentals of inductance, etc. Fig. 9 displays a piece of written work of an individual for problem 1 in the second midterm exam. Classroom discourse plays an important role to help internalize learning. It requires that students engage in scientific ways of asking questions, exploring and explaining ideas, and reviewing possible solutions while working on problems in teams. Students are able to do so only when their group talks are tied to authentic classroom discourse that deepens conceptual understanding. Working on problem 2 in the team test offered students the opportunity to learn content knowledge through dialogues among students and between the instructor and students. It helped students take up their learning. By reviewing individuals' midterm exam papers combined with their verbal discussion, we learned what worked and what did not work and gained some insights into the development of classroom discourse.

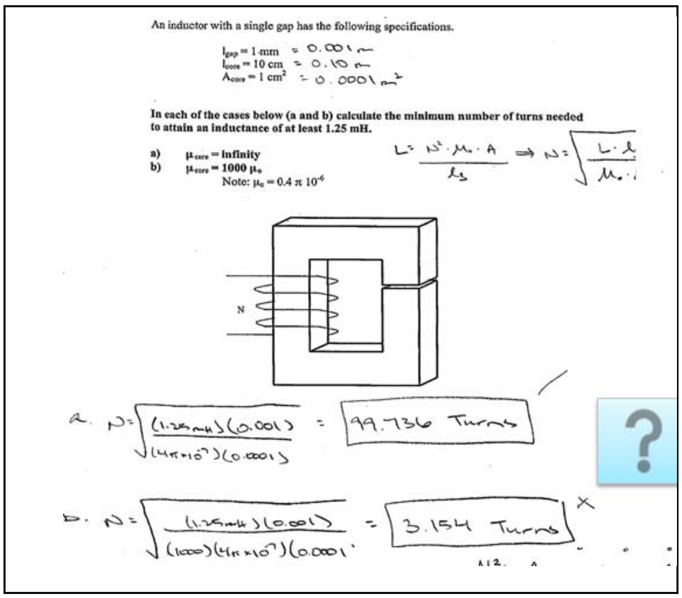

Fig. 9. Individual's work of Problem 1 in the second midterm.

IV. DISCUSSIONS AND CONCLUSIONS

Student verbal discourse is at the center of classroom discourse development. The development of classroom discourse demands and relies on the learning environment as emphasized by socio-cultural theory [16] [22] [23]. It underscores the joint effort from the instructor and students, particularly the role of instructor as we discuss in the following.

A. Critical Role of the Instructor

As was shown in our previous study, instructor experiences provide the topics for learning, which is critical for the instructional model implemented in "flipped classrooms" [8][13]. This study found that instructor experiences determine how problems are framed, which is also critical in facilitating students' talking and learning. Problems posed in group discussion sessions must not only stimulate student interest, engaging cognition, but also provide challenges appropriate to individual students' current abilities [11]. To achieve this goal, both content and delivery are counted. The practice of "anticipating" is designed to accomplish the task [7]. Working on problems posed by instructors should encourage collaborations among students in constructing shared understanding of content knowledge and skills. In other words, instructors' expericnes generate and deliver real questions entailing both content and representations for authentic classroom discourse development and learning.

B. Joint Effort That Influences the Development of Classroom Discourse

Our study indicated that talks from the instructor are important for the development of classroom discourse. Because the interactive and dialogic nature of classroom discourse dictates what the instructor says and how the instructor says it, classroom discourse is built on responsive teaching and learning. Students are encouraged to take responsibility for their own learning and participate in group activities while instructors are required to become an active member that not only initiates but also contributes to classroom dialogues. After students exhausted their ideas, for example when working on problem 2 shown in Figure 8, they were ready for talks from experts to further their understanding and to learn to be responsible to norms of the field. From this perspective, contextualized lecturing from the instructor is an essential component of classroom discourse.

C. The Instructional Model and Classroom Discourse in "Flipped Classrooms"

The Four-Practice Model was designed to empower instructors to turn classroom interactions and communications into effective pedagogical tools in problem-centered learning. It supports the development of classroom discourse for flipping lectures in multiple dimensions as illustrated in Figure 1. The development of classroom discourse is at the center of this instructional approach. The three practices of the model, monitoring, connecting and contrasting, and contextualized lecturing, take place in "flipped classrooms" to support in-classroom face-to-face talks while the practice of "anticipating" contributes to the verbal classroom discourse directly in a way influencing the authenticity of discourse: content to be problematized and framed for classroom talks. Tables I and II summarize how the instructional model shapes the development of classroom discourse and how classroom discourse ensures instructional practices that facilitate learning in "flipped classrooms".

V. SUMMARY

For years engineering educators have observed that the ways in which the content of problems is framed affect student learning. This was our first study in which we were able to analyze data both qualitatively and quantatively. It showed that the way in which content is problematized influences student learning in significant ways just as the content itself does. From models and modelling perspectives for engineering education, cognitive aspects such as representational fluency while interacting with learning enviornments including materials and artifacts are critical in fostering the development of discourse that facilitates communicative teaching and learning [24] [25]. We are still in the process of transbribing massive data sets and expect to collect emerging evidence to improve classroom discourse development to promote active learning. Students have told us that the new instructional appraoch in "flipped classrooms" helped generate learning interests, change learning beliefs, and imporve learning habits [8]. We recognize that both students and instructors are offered a unique opportunity to reach the important educational goal of maximizing learning potentials while recognizing gaps between the level of students' learning and the potential of their learning. "Flipping lectures" sets a context to meet this goal through the joint effort supported by the Four-Practice instructional approach.

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