The Discourse of Engagement: An Approach to Analyzing Conceptual Understanding In An Inquiry-Based Learning Environment

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Abstract – Engineering educators are increasingly being encouraged to adopt instructional methods that engage students in authentic activities to foster inquiry and deeper conceptual understanding. However, a significant challenge facing professors who would like to incorporate such methods into their teaching is a lack of understanding of its basic principles, mechanisms, and features. This paper reports results of an innovative means of investigating promising approaches to inquiry-based teaching/learning in undergraduate engineering courses at an urban research university on the U.S.-Mexico border. The research design incorporates analysis of natural language data from classroom interaction to shed light on teaching and learning practices that show promise for fostering enduring conceptual understanding. Highlighted are the classroom practices of one professor who designed and implemented a problem-based case in an undergraduate industrial engineering course, which the researcher video-taped and transcribed. Linguistic analysis of this transcript provided descriptions of instructional practices that encourage learners’ engagement with key concepts. Implications of the analytical approach are drawn for the investigation of conceptual understanding and the design and refinement of inquiry-oriented classroom practices.

Index Terms – Conceptual understanding, discourse analysis, inquiry-based teaching, undergraduate learning.

INTRODUCTION

For some years, pedagogical experts have been calling for improved teaching methods in STEM courses for undergraduates, using student-centered, inquiry-based approaches that encourage deep conceptual understanding and application of theoretical principles to authentic problems [1,2]. There is mounting evidence that where inquiry teaching methods have been applied, students may perform better on standardized exams, as well as improve their understanding of fundamental concepts and principles [2]. Moreover, studies suggest that these newer approaches may foster student persistence, especially among underrepresented groups [2,3]. Nevertheless, such approaches have still not seen widespread adoption, and traditional, lecture-based instruction is still prevalent in engineering education. A significant challenge for professors who may wish to try new methods is a lack of understanding of the basic mechanisms, features, and organization of instruction designed to foster greater inquiry, stronger engagement, and deeper understanding.

The purpose of this paper is to outline a discourse-based approach for analyzing the features of instructional methods and techniques in STEM disciplines. While the analytical approach itself is neutral in terms of the goals and outcomes of instruction, it is being developed and operationalized in the context of a NSF-funded study with a dual focus on: 1) students’ development of engineering literacy and conceptual understanding within an inquiry-oriented environment; and 2) faculty development of teaching methods for fostering such learning. The sample of instruction analyzed in this paper represents one set of promising practices for supporting students’ engagement around key statistical concepts in an industrial engineering course, while it also affords a glimpse into students’ understanding and process of meaning-making at a specific moment in time.

THEORETICAL FOUNDATIONS OF THE STUDY

In sociocultural learning theory [4], learning is understood to occur in and through social interaction. Research on classroom learning and pedagogy that is based in sociocultural theory generally foregrounds the role of language (and other semiotic systems) because it is the most significant and prominent of the mediating tools through which learning occurs. As Vygotsky described it, an individual’s development of higher mental processes, such as the ability to reason and make inferences, occurs concomitantly with the development of more complex language functions. Sociocultural approaches to studying the interplay of language and learning at the university level are based on the understanding that language use and academic literacy development become increasingly specialized and technical as one advances in the academy [5]. Academic disciplines have developed characteristic ways of encoding, expressing, and disseminating disciplinary knowledge that distinguish them, one from another. Such disciplinary discourses are markers of professionalization and they may...
represent barriers of access to the discipline to novice learners. Becoming literate in academic and other specialized discourses is crucial for social advancement, and it is a complex, lifelong process. For this reason, scholars in the learning sciences and literacy education who are concerned about improving equity and access in education are engaging in research that aims to describe pedagogical discourse, which in turn will help to inform the development of practices that raise students’ metadiscursive and metacognitive awareness [6-8].

**THE CONTEXT OF THE STUDY**

*The Discourse of the 2020 Engineer Project*

The study presented here is part of a three-year, NSF-funded project to develop and implement inquiry-based instruction around cases designed to stimulate students’ thinking through counter-intuitive and model elicitation-type problems. It represents a collaboration among co-principal investigators in education and engineering. Engineering faculty involved in the project have agreed to develop such cases and participate in a process of reflection, both individually and collaboratively, around their implementation and refinement. The engineering faculty participants include two principal investigators, five other faculty representing a variety of STEM disciplines at the University of Texas at El Paso (UTEP), and ten engineering faculty at five partner institutions located in the southwest U.S. In the March 2007, during the first year of funding of the project, these faculty met for a two-day workshop to begin to develop cases. Since then, the faculty have continued to collaborate through monthly virtual meetings, sharing challenges and successes in developing and implementing the cases, and with their teaching in general.

The education faculty serving as co-principal investigators facilitate and evaluate the faculty development process and also investigate the effects of changes in instructional practice on students’ development of conceptual understanding and fluency in engineering discourse. The analytical approach illustrated in this paper is designed to provide engineering faculty with practical information about the effects of the interventions and changes in practice they are implementing so that they may further refine them. To date, the collection and analysis of data to evaluate the project has focused on faculty and classrooms at UTEP.

**Study Participants**

The faculty member whose classroom experiences provided the examples analyzed below is a tenured associate professor of industrial engineering who has eight years of teaching experience. He was motivated to participate in the project out of a strong desire to make a difference in engineering education and to provide the best possible learning experiences for industrial engineering students at UTEP. Like the vast majority of engineering faculty, he felt his preparation in the discipline of industrial engineering had been strong, but he lamented that he had had no training whatsoever in pedagogical theory and methods. In this void of experience and information about effective approaches to teaching, he began his teaching career mimicking the teaching methods he had experienced as a student, by delivering the course content mostly through lectures, supported by slides, and using as the primary form of assessment multiple choice tests of procedural knowledge in problem solving. As Lortie [9] has noted, this professor’s early experiences in teaching are not uncommon: many teachers at all levels learn to teach primarily through their lengthy apprenticeships as students.

The student participants in this study are industrial engineering students. Students in this major at UTEP are predominantly Mexican or Mexican American, and in both semesters in which the class has been observed as part of this project, the vast majority of students were native-Spanish speakers, in greater proportions than in other engineering majors. The popularity of the IE major among Mexican-national students, who pay in-state tuition at UTEP, is probably explained by the strong demand for IEs to work in *maquiladora* manufacturing and assembly operations that comprise the economic base of El Paso’s sister city, Ciudad Juarez, just across the border in Mexico. The sample of classroom discourse analyzed below in the Analysis of a Whole-Class and Small-Group Discussion was taken during the Fall semester of 2007, the second time the case was implemented. During that semester, there were 25 students enrolled in the course, 19 of whom were male.

**Systems Engineering and the Problem-Based Case in Statistical Inferencing**

Concomitant with his decision to participate in this project, this instructor made several changes to his teaching of the focal course in Systems Engineering, a course for upper division majors, generally taken in the junior or senior year. Throughout the first semester of his participation in the project, the instructor began to regularly implement more hands-on activities in the class, which he interspersed throughout his lectures so that after introducing a set of concepts in lecture, he had students engage in some sort of practical application of the ideas. He specifically included more in-class activities that practiced skills and concepts students would need to use in the semester-long product redesign team project that serves as the capstone assignment for the course. He also designed a practical, problem-based case to help students learn key concepts in statistical inferencing, which he has implemented twice to date, in the Fall semester of 2006 and again in Fall 2007. The evaluators have observed and video-recorded the implementation of this case both times. Details of the goals and methods of implementation of the case will be described further below.

Along with these changes in instructional practice and in response to faculty development initiatives within the project, the instructor began to write reflections after each class in which he described his goals and objectives for the class session and analyzed how well he felt that they had
been met. He shared these reflections with the co-PIs in education, who shared with him some of their notes of their classroom observations and reacted to his reflections.

In the latter half the first semester of his participation in the project, the instructor implemented a problem-based case in statistical inferencing that he had developed prior to the start of the semester. The implementation of the case and subsequent “reporting-out” activities took place in phases over five, 75-minute class periods. The phases of in-class activities that took place as part of the case were:

1) Discussion and review of key background concepts in statistics, completed as a whole class and in small groups – Days 1 and 2;
2) Enactment of part 1 of the case activity, in small groups – Day 2;
3) Presentation of the findings, group by group, for the whole class – Days 3 and Day 4;
4) Enactment of part 2 of the case activity, in small groups – Day 4;
5) Presentation of the findings, group by group, for the whole class – Day 5.

The case had groups of five to seven students playing the roles of shop floor supervisors, inspectors, and operators attempting to measure, explain, and ultimately reduce “errors” in a process designed to mimic, in a simplified way, the types of processes and systems that industrial engineers are typically charged with improving the quality of. The shop floor activity took place in two rounds in different two class periods. After each round, the student groups were directed to prepare a written report to tabulate the data they had collected during the activity, describing in statistical terms what they had found. They also needed to prepare and make an oral presentation of their findings, showing the relevant data in PowerPoint slides. This reporting-out activity took one class period after each of the two rounds of data collection.

In addition to these in-class activities that comprised the case, there were several written homework assignments. For example, the instructor had students write journal-type reflections after each class and submit them electronically to him. The purpose of these homework assignments was to encourage students to summarize and synthesize the ideas discussed in class and also as another way to gauge their understanding of the key concepts.

THE RESEARCH DESIGN AND ANALYTICAL APPROACH

This study employs a discourse analytic approach to investigating the structure, functions, and outcomes of instructional choices and their moment-by-moment realizations in classrooms. The particular elements of discourse in focus in this study of inquiry-oriented teaching and learning are pedagogical genres, participation frames, and interactional moves, a framework I have adapted from Wells [10]. I define pedagogical genres as relatively stable, goal-oriented, recurring constituents of classroom (or laboratory) practice, such as lectures, laboratory experiments/exercises, whole class discussions, small group discussions, or debates.

Participation frames provide structure for interaction; they are defined by certain types of role relationships, turn taking conventions, and uses of tools and technologies in the process of teaching/learning. A common participation frame for a lecture, for example, would be one in which the lecturer dominates as speaker, while the audience listens. In this participation frame, an audience member might raise his or her hand to make a bid to ask a question of the lecturer. The relationship between the lecturer and the audience is typically one in which the lecturer is assumed to hold knowledge or information that the audience members want or are perceived as needing to have, and that knowledge/information is transmitted to the audience through the lecturer’s speech, perhaps augmented by written or graphical information presented in slides.

Pedagogical genres and participation frames are generally part of the instructor’s planning process, whether consciously so or not. Ofentimes, participation frames become so routinized that the instructor and students orient to them without being conscious of doing so. Nevertheless, along with the choice of pedagogical genre, the participation frame is an aspect of the organization of classroom activity that instructors may have a great deal of conscious control over. Participation frames may shift several times within a given class session, and may even be allowed to shift in the moment in response to learners’ needs, if the instructor is flexible and especially if s/he permits or expects learners to play a proactive role in their learning processes in the classroom. In inquiry-oriented classrooms, as compared to more traditional, lecture-based teaching, participation frames often encourage students to take more and longer turns at talk and to have greater control over the topics and the flow of discussion.

At the level of the interactional move, however, most instructors do not typically make conscious decisions, except in the case of a scripted lecture or some other form of scripted instruction. This is the level at which pedagogy is encoded into utterances. It is the “what” and the “how” of instructor-student talk in the moment-to-moment flow of activity and interaction in the classroom. Analysis of interactional moves examines such aspects of discourse as question types, forms of responses, and inflection, intonation, and gesture. Each move may influence what is sayable afterward. It is at this level that instructors who are consciously attending to what students are saying may be able to make some inferences about what they think and know.

Data collection around the implementation of problem-based cases in the larger project has involved videotaping in three faculty participants’ classrooms to date. In addition to these videotapes, data include audio-recorded interviews with the faculty participants and with several students in each class. Student conversations during group activities have been audio-recorded. A variety of other data have also been collected, including students’ written project reports,
slide presentations, written homework assignments, exams, and other written products. The data analyzed for this study were collected through videotaping and direct observation by the author. The videotapes were subsequently transcribed, following conversation analytic transcription conventions [11], capturing not only the words spoken, but also relevant paralinguistic features, such as intonation, pauses, and gestures.

Data analysis proceeded from a grounded theory approach [12], identifying genres, frames, and moves that resulted in students expressing conceptual understanding in the form of definitions, examples and explanations. Using discourse analytic techniques [13], specific interactional moves that preceded such expressions of conceptual understanding were identified for linguistic analysis. Several examples of genres and specific moves that have elicited a good deal of students’ expressions of conceptual understanding have been identified already in this ongoing project. Some of the genres analyzed have included group oral presentations, group problem solving activities, and an innovative genre that has students take sides on an issue or problem, physically moving to one side or the other of the classroom in order to physically demonstrate their stance on the issue. However, for purposes of illustrating the analytical approach, one instantiation of a familiar pedagogical genre was chosen for this study, a whole-class and small-group discussion session, using participation frames that encouraged students to articulate their understanding of the concepts being discussed. Portions of transcript from one segment of that session, when the class was discussing different kinds of samples, are excerpted below in order to illustrate an analysis of interactional moves and the linguistic forms that students’ expressions of conceptual understanding may take.

**Analysis of a Whole-Class and Small-Group Discussion Session**

Leading into the second implementation of the problem-based case, the instructor employed a hybrid pedagogical genre: a whole-class and small-group discussion that lasted for one and a half class periods, approximately one hour and 45 minutes. His purpose was to review key concepts in basic statistics, to activate and gauge the extent of students’ background knowledge of such concepts as sampling, error, bias, variability, and representativeness. The instructor believed these were concepts that the students should have been familiar with from a prerequisite course in probability statistics. The class repeatedly shifted between two participation frames in this discussion session, a whole-class interaction format, in which the instructor controlled turn-taking as well as the topics that were discussed, and small-group discussion, initiated and partially facilitated by the instructor, but in which students themselves controlled turn-taking and topic nomination. It is important to note that in small group interactions in this class, students often codeswitched between Spanish and English, except when they were aware that the instructor was listening in, in which case they would generally switch back to using English exclusively. When students were speaking Spanish, they had greater control over the topics they discussed, as the instructor does not speak Spanish and could not know if the discussion remained on the topic he had nominated or not.

In the whole-class participation frame, the nomination and framing of topics was mediated by questions the instructor posed, orally and on slides, such as, “What is a sample?”, “Why do we need samples?”, and “What do we do with samples?” Some slides contained short scenarios with questions that required students to apply the concepts they were discussing. One such scenario read, “Imagine that 10,000 lottery tickets have been sold. Five winners have to be chosen. What’s the fairest way to choose the 5 winners?”

The shift to the small-group participation frame was initiated by the instructor when he asked students to discuss these questions in small groups which students formed ad hoc among the classmates who were sitting in close proximity. These loosely structured groups ranged in size from three to six students. The shift back to the whole-class participation frame was again initiated by the instructor when he asked for a spokesperson in each group to report their answers to the rest of the class. The role of spokesperson for the group was not formally assigned. In some cases, the instructor chose a student to call on, and in others, a student self-nominated to speak for the group.

Within the whole-class participation frame, the instructor would often call on more than one student from the same group, and sometimes more than one group spokesperson would self-nominate to share ideas discussed by the group. By the end of the class, 18 of the students, roughly 75% of the class, had spoken on record during the whole-class discussion. During the small-group discussions, all students contributed to the discussions, though a detailed analysis of the forms and patterns of discursive participation within these groups has not yet been undertaken.

In terms of interactional moves during the whole-class discussion, the professor illustrated several types of moves that elicited students’ expression of their own or their groups’ understanding of the concepts under discussion. One of the most significant types of these moves was premeditated: he had prepared slides containing guiding questions and describing authentic scenarios that asked students to apply the concepts under discussion. He read these slides aloud and then directed students to discuss the answers in their groups, while the scenarios and questions remained on the screen for them to refer to. In that way, he guided their discussion toward the concepts that he felt were important for the class to understand as background for entering into the problem-based case activity. He orally rephrased the questions on the slides in several ways, which helped students to interpret his meaning. For example, with a slide that read, “Are there different kinds of data? What are they?”, he said:

> What I want you to do now is form your local team, just like last time, and I’ll give about five minutes or so. I
want to know from you if there are different kinds of data, and what are they? Think of all the kinds of data you have encountered. What do you think are some types of data? … Make a list of the kinds of data you have encountered in practice … What do you think are the kinds of data? Are there different kinds of data? … You were collecting data too in your project. That’s one type of data.

With this move, the first small-group discussion topic on the second day of discussion, he drew students back into where the discussion had left off from the previous class period, and he helped them to focus on the topic at hand. With his reference to the data they were collecting in a semester-long project, he helped stimulate their background knowledge of “types of data.” Another type of move he made that opened up participation, and that encouraged risk-taking with answers, was the way in which he drew the groups back into the whole-class participation frame by asking an open-ended question. For example, after the groups discussed different types of data for about four minutes, he drew them back into the whole-class format saying:

Okay. Let’s start hearing from each of the teams here. Want to go first, Cristiano? What did your team come up with?

The prompt, “What did your team come up with?” encouraged students to relate any ideas they had discussed, whether or not they felt they had a “correct” answer. In fact, in this case, Cristiano’s answer for his group did refer to “types of data” the students were collecting for their semester-long project, such as survey data of customers’ needs and product benchmarking data. As valid “types of data” the instructor acknowledged this response and said they’d return to discussing them. He then continued to elicit other groups’ answers. When Corina mentioned that her group had discussed “measurements,” the instructor responded:

Instructor: Measurements. What do you mean by that?

Corina: Uh, like based on some data, linking up from some measurements.

Instructor (to Corina): Okay, give me one example of a measurement.

Daniel (Corina’s groupmate): Well, for example a numerical measurement.

Instructor: Okay, so, numerical data. Any other types of data?

Corina: Uh, we had category, where we divide it up depending on what characteristics they have.

The instructor then probed her further for an example of categorical data. After waiting for several seconds, he opened the question to the whole class. Fernando then offered “height” as an example of categorical data, and without ratifying this answer, the instructor probed him further:

Instructor: So, how would you classify the height?

Fernando: The height? You put them in groups based on height.

Instructor: But you actually, say, measure those, right?

Fernando: Mhm.

Instructor: Wouldn’t you have numbers?

Several students: Yes.

Instructor: Is that category?

Fernando: Uhm…

Several students: No.

Fernando: It’s numerical.

The conversation continued with three more students from different groups offering examples that they believed to be categorical data, but which upon closer scrutiny through probing questions from the instructor, they later recanted. With each of these examples, the instructor held back on ratifying the examples as “correct” or “incorrect,” and instead probed the responding student for additional information, causing them to consider their ideas more deeply and at the same time, to externalize their thinking in speech. Then Alex offered “eye color,” to which the instructor responded:

Instructor: Eye color. How would you categorize eye color?

Alex: See, you have brown eyes, blue eyes, green…

Then, without further comment from the instructor, Alex’s answer seemed to open the floodgates, and his classmates started calling out further examples of categorical data, such as ethnicity, religion, marital status, and political party affiliation. What’s important to note about the moves this instructor made is that his questioning strategy focused on eliciting responses from multiple students, without judgment of whether they were “correct” or “incorrect.” Guided by the instructor’s probes for examples and explanations, the students were eventually able to co-construct examples of
categorical data. After engaging in a similar round of brainstorming about examples of discrete and continuous numerical data, the instructor displayed a slide that described several different types of data collected about cranes at the Annual Festival of Cranes in nearby Socorro, New Mexico, and students were able to correctly identify which ones were categorical and which numerical, and within the numerical types, which were discrete and which were continuous.

**DISCUSSION AND IMPLICATIONS**

The preceding analysis described a common pedagogical genre applied within a student-centered, inquiry-oriented classroom. By shifting between whole-class and small-group participation frames, the instructor encouraged active participation from all students in the class in a discussion of basic concepts as a lead-in to a problem-based case activity. The analysis revealed several types of interactional moves within this discussion that served the purpose of eliciting students’ understandings and misunderstandings of key concepts. By accepting students’ responses without ratifying them, and then probing the students to provide explanations or examples, this instructor guided students’ expression of ideas in ways that enabled them to build upon one another until there appeared to be a general consensus in the class.

Nevertheless, a few caveats about this discussion and the limitations of the analysis are necessary. First of all, not all students’ voices were represented in the whole-class discussion, and as a co-constructed discursive event, although the class appeared to come to some common understanding, it’s not possible to discern what all students were thinking or had learned at the discussion’s culmination. Assigning the reflective piece of writing about the concepts covered in class as homework was one means by which this instructor addressed that dilemma.

With regard to this instructor’s practice, it’s also important to note that this analysis represents a “snapshot in time.” This professor, along with the other faculty members participating in this project, is in the process of discovering what inquiry-based pedagogy means in engineering classrooms. All of the faculty participants in the project are still experimenting with different kinds of practices that may foster deep conceptual engagement in learners. The aim of this study was to illustrate an approach to analyzing such classroom practices that may be used to inform faculty development within our project and for the broader engineering education community. It is hoped that analyses such as the one illustrated in this paper will help faculty to discern and be able to adopt/adapt strategies and practices that show promise for fostering students’ deep conceptual engagement and enduring conceptual understanding.

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