The Discourse of Engineering: The Role of Language and Authority in the Learning Process

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Instructional design based upon situated learning theory includes authentic activities, contexts, and assessments. It provides collaborative knowledge construction and opportunities for explicit articulation of knowledge during the learning process. Most efforts to provide these elements are focused on upper level courses. Providing them at lower levels of the curriculum is problematic since the traditional assumption is that students must learn disciplinary fundamentals before they can successfully attack significant open-ended problems. How can students solve difficult open-ended engineering problems before they've actually learned some of the engineering they need to know in order to solve them? The application of deep "learning by doing" practices early in the curriculum may have limitations.

Background

Over the past four years we developed, taught, and assessed a new curriculum for our sophomore chemical engineering courses. We taught separate sections of demographically similar cohorts where one section was taught traditionally and the other was taught using what we called a project-based, spiral curriculum. The major new features were a restructuring and spiraling of specific chemical engineering topics around a framework of open-ended, team-based projects. In the following we will refer to the group that took the new curriculum as the spiral-taught and the traditionally taught students as the comparison. Note that "spiral-taught" is a convenient term we use that includes all the teaching and curricular changes implemented during the project, not just the spiral topic structure.

The spiral curriculum was delivered through a variety of channels including cooperative-group projects, traditional lectures, homework problems, in-class active learning sessions, interactive multimedia learning tools, and laboratory experiments. To assure individual accountability, individual homework grades were recorded and individual tests were given throughout the year. A thorough understanding of the projects prepared students for most of the material on the tests, but some material was covered only in supplemental lectures and homework problems. Details of our curriculum design, delivery methods and our implementation experiences are available elsewhere.[1, 2]

Our overall project assessment goals were to evaluate how the project-based, spiral curriculum affected students' ability to: solve problems at several levels of cognition, work in teams, work independently, master the fundamentals of chemical engineering, and integrate material from several courses. We were also interested in how it affects student attitudes and satisfaction about chemical engineering and their professional development within the discipline. External consultants were used to provide objective assessment through a variety of qualitative and quantitative measures. These included surveys, interviews, videotaping of class and project work, end-of-term course evaluations, grades in follow-on upper level courses, a novel sophomore process design competition, and an end-of-year comprehensive exam.

All of our product-oriented data demonstrated that spiral-taught students learned the fundamentals of chemical engineering better than comparison students, had better attitudes about the discipline and their choice of major, had higher retention rates in the major, and performed at higher levels in junior and senior year courses. The assessment details related to these measures are provided elsewhere[3]. These results pointed to the quality of the product but they told us very little about the learning process. We were really interested in understanding more about what goes on during team-based problem solving, how students demonstrate their learning, and how that relates to the curriculum.

Methodology

At the end of each implementation year we held a team-based problem solving competition. All sophomores were invited and the participation rate exceeded 90% of both cohorts. Spiral-taught and comparison students were placed in separate teams. Teams were randomly assigned (within a cohort) and were heterogeneous relative to race, gender, and ability. All participants were paid and the winning teams from each group were awarded prize money. Teams were given an open-ended chemical process problem to solve and had two hours to develop their solution. Each team selected one member to present their solution. These 10-minute presentations were videotaped. The presentation videotapes and written student work were sent to three external experts in chemical engineering. Judges were given the problem solution, some rubrics for rating student work, and a form to report their analysis of each team's solution. These judges ranked all teams from best to worst, on the basis of the technical work, not the presentation quality. Judges were volunteers from academia and industry and had no knowledge of whether the teams were spiral-taught or comparison.

All of the two-hour tapes of the problem solving sessions were transcribed. We then analyzed the problem solving sessions by viewing the tapes, using the transcripts as a guide. Our methodology derived from the techniques of video interaction analysis .[4,5] An interdisciplinary team comprised of a chemical engineer (DiBiasio) and a developmental psychologist (Comparini) analyzed the tapes.

The chemical engineer examined the students' technical approach to problem solving. He was interested in learning what technical decisions prevented groups from making progress, how successful groups negotiated those critical problems, and why less successful groups became stuck. Of particular interest was understanding what topics were troublesome for most students (problem definition, thermodynamics, writing material balances, etc.). We also wanted to know whether group progress was stimulated by a single "smart person" in the group, or were other intellectual processes dominant. The developmental psychologist analyzed interactive and communicative patterns. Her interest was in understanding team dynamics, how students interacted during the session, and how their discourse affected the solution process. We expected things like dominant personalities, gender, and motivational issues to play a significant role in team function.

We are convinced that, at a minimum, both types of expertise are needed to do this analysis and that there should be a gender mix in the analysis team. Both people must view the tapes together, and with the transcripts, do the analysis as a team. It was clear throughout the analysis process that neither person could have successfully done a proper analysis in isolation. This method, though labor intensive and time consuming, was necessary to probe the richness and complexity of the learning process.

Results

Firstly, it is important to know that external judging of the problem solving competition showed that there was a significant positive difference between spiral-taught and comparison teams. Perhaps this is not surprising since spiral-taught students had more group learning experiences. However, the comparison cohort had several team experiences during the year. What surprised us was the degree of difference between the two cohorts. We concentrated our efforts on trying to understand this difference.

A second surprise was the absence of traditional teamwork problems. Our initial analysis focused on some traditional issues such as intellectual dominance by one individual, gender issues, personality dominance, lack of effort, or team antagonism. It became clear that none of these issues were particularly salient. More importantly, we did not find any differences between comparison and spiral-taught groups.

Our next level of analysis was a broad look at quantifying the discourse among groups by analyzing the transcripts. This is best illustrated by example. We looked at four rough measures of group interaction: amount of talk (measured by number of turns per group), proportion of turns taken by each group member, use of questions, and the stasis or fluidity of roles. Table 1 shows a typical comparison of one spiral-taught group and one comparison group. The numbers shown are representative of all other possible comparisons.

Table 1. Typical Comparison of Amount and Distribution of Talk Among Group Members

	Spiral-taught team	Comparison team
1. Amount of talk (# turns/group)	1877	1141
2. Distribution of talk (% of total turns)		
Speaker 1	33	30
Speaker 2	37	31
Speaker 3	30	39
3. Number of questions	523	311
4. Role fluidity	Fluid	Somewhat static

This analysis showed that there was a higher level of talk in spiral-taught teams, and that more questions were one characteristic of that discourse. There was generally a greater fluidity of roles within spiral-taught groups, and comparison team members tended to remain in one role within the group. It was also clear that in all teams there was a fairly even distribution of talk among team members and there were no real differences between cohorts. However, this type of analysis is severely limiting if one is interested in probing learning. For that we must summarize the results of the videotape analysis.

It is difficult to present the results of video analysis within the constraints of a conference paper and in the absence of the important visual elements of communication. Transcript samples must be presented out of context, and for space reasons we must summarize and use illustrative examples. The examples and descriptions provided below are, however, representative of each cohort. Here we try to show how students' relation to authority, exemplified by their language and positioning relative to professional tools, tends to classify teams into two types of groups. By authority and tools we mean the teachers, textbooks, data sources, and software that are part of the discipline.

The most obvious authority figures are the professors whom the students have had in class. We analyzed the transcripts of 7 teams (4 spiral-taught and 3 comparison) looking for references to faculty. Each transcript represented two hours of videotape and was typically about 30 single-spaced pages. In the samples below comparison teams are boxed with a solid line while spiral-taught teams are boxed with a dashed line.

Comparison teams referred to specific faculty members and courses 6-10 times during the sessions, while spiral-taught teams had 0-3 such references. Comparison teams frequently referred to content matter using the teacher's name rather than the subject. For example (Prof. Clark taught thermodynamics and Prof. Engwall taught staged-separations):

Fred: No, it's just one million pound mole per hour coming out of that bottom stream. Of the stream that's 99% pure formaldehyde.
Rob: [overlapping] Wait, why do you…
Tina: [overlapping] Oh, oh, oh you're right. You're right, you're right. Okay. Um… Okay. Do they tell us anything else.
Rob: Alright, so we don't, in this we don't need any, like, Engwall stuff. We're not thinking Engwall, we're thinking like…
Tina: Way back, yeah.
Rob: Professor Clark's class.

And, further in the tape:

Rob: What were those charts we used?
Tina: Those will give you little K, and you can find X and Y from little K.
Rob: We, aw, crap.
[pause]
Rob: We need all that Clark stuff, I think. Remember those graphs we used, all that stuff how to find K, the ones with the [inaud] quotients.
Mark: [overlapping] the DePreist one? The one with the lines?

No significant progress in problem solving resulted following either of these exchanges. Students' distance from the material is demonstrated by reference to the teacher, and even when the correct course material was identified, they could not use the information in any useful way. In some cases these teams referred to the color of a textbook or a professor's name in attempting to articulate that what they really needed to do was write a material balance. Yet the term "material balance" never appeared. We did not find such examples in the spiral-taught team transcripts.

The use of the word "we" is very often another clue about how students position themselves. In spiral-taught groups, "we" is nearly always used to represent the team working on the problem. As in:

Fran: Oh, yeah.
Mark: [inaud] So basically we have an extraction. Of a gas.
Fran: Yeah.
Rick: There's gonna be multiple… well, first we have to run it through a reactor.
Mark: [Well, yeah. I'm just trying to. Methanol run through the reactor. Keep going, (Fran)? *guess*]
Rick: So wait, we have…
Mark: Methanol and [inaud]
Fran: Oh, [inaud]
Mark: Yes.
Fran: [I'm thinking of digging up [inaud] *guess*] Do we want to choose the temperature?
Mark: Well, basically it's going to be exothermic so we're to take some of that… And react it with [some products and see what happens *guess*].
Rick: So we just feed… methanol in?
Mark: Yeah, methanol in.
Rick: Oh, and we'll have to calculate delta H of that reactor. Formaldehyde and hydrogen.

However, comparison teams frequently used "we" to include a course (authority) reference:

Heather: what is? .i don't understand what this right here [gestures toward paper] the thing about [inaud] process is.
Bob: .i don't know. .we didn't talk about that at all did we?
Heather: .i really don't think so

and later…..

Rob: Wouldn't it just be delta heat of formation of methanol.
Mark: No, heat of formation is when you're going from…
Fred: [interrupting] Heat of formation is when you're…
Mark: [interrupting] That would be like, that would be like delta H like going from standard to a higher temperature, heat of formation is the correction factor in between.
Fred: Have we ever done what you're talking about?
Rob: What I am trying to say…
Fred: Have we ever done that, have we ever done what you're talking about?
Rob: Yeah!
Fred: When?
Rob: Like say you got water, I don't know.

During the problem solving sessions, laptop computers were available for every group. Most groups chose to use them in some fashion. Typically, spiral-taught groups decided what set of equations needed solution, then set about using MathCad or Excel to crunch the numbers. For example:

Mark: We have to set up the reactor first anyway.
Fran: I mean for the calculations.
Mark: What are we going to calculate?
Rick: We're going to calculate the equilibrium.
Fran: [overlapping] We're need to calculate epsilon… so we need the information. What book is that in?
Mark: We have that here.
Rick: No, we have to do the calculations.

This was also the case with one of the comparison groups, but the other two comparison groups looked to the computer for the answer rather than deciding on a path to the answer that might be more efficient using the computer. An example was:

Tina: Can we, like, pick a temperature?
Mark: That's what I'm trying to see [inaud].
Rob: [overlapping] Maybe we should try and use Excel. Do we have Excel?
Tina: Yeah, I'm looking for MathCad so we can stick it in MathCad.
Rob: Wouldn't we want to stick it in Excel?
Tina: Do you know how to do it?
Rob: [overlapping] We can do different… I can do it, yeah. Where is that equation? Do you have it in your notes? (Tina)?
Tina: What do you want?
Rob: Do you have ah, oh here it is. Wait, I'm almost there. Oh, oh oh…

In this case, the group really needed to simply examine the reaction given and use LeChatelier's principle to pick the temperature. No calculations were needed. Consider this exchange in a spiral-taught group, at the same point in the solution process:

Mike: What would be better to pick, one bar or five bar?
Liz: I don't know if one bar makes our…
Joe: [interrupts] Oh, wait. By LeChatlier, higher pressure favors…
Dave: [inaud]
Mike: [overlaps] [inaud]
Joe: Okay, so we don't. Lower pressure is not good.
Dave: And then the reaction…
Joe: So let's see- which one's exothermic? We have to figure out whether this reaction is endothermic or exothermic and see whether higher temperature favors it? If it's endothermic we want the temperature to be high, if it's exothermic we want the temperature to be low. So let's do… Let's find the heats of formation.

These examples, and the many more available in the complete transcripts led us to generalize that despite a continuum of behavior, there were really two classes of teams. It became clear to us as we examined several hours of tape that group problem solving was more advanced when students participate in a "discourse of engineering" that includes particular kinds of verbal communication, the use of discipline-specific tools (charts, tables, diagrams) and a general identification with the chemical engineering discipline. Successful teams used language that aided them in constructing a public object of scrutiny that can be questioned and revised by group members. They used authoritative sources such as the professor, texts, tables, and published data as potentially useful resources, and generally took a stance of authority. Conceptually and through language they situated themselves as *chemical engineers* attacking a problem. In contrast, less successful teams sought answers from authoritative sources before publicly constructing a framework within which to evaluate contributions by group members.

Very often their framework was naively built or it contained errors that were not recognized, challenged, or modified. Such teams situated themselves more as *students* of chemical engineering, searching for a solution rather than constructing one. Their language reflected distance from the discipline, and frustration and difficulty with their relationship to authority.

We believe that the observed learning process directly results from the students' educational context. Throughout the year, the spiral-taught students had written and oral communication that essentially asked them to pretend they were in a working environment. All project descriptions were transmittal memos written from fictitious company executives to design teams. All projects were industrially relevant problems that were always put in the context of a company needing a problem solved or a new design developed. In one project we asked students to put themselves in the role of teachers and design a laboratory experiment for the following year's class. When coupled with frequent open-ended problem solving, cooperative learning, and the spiral topic structure students learned chemical engineering better than in the absence of these items. Our assessment design could not probe individual effects, so we can only hypothesize about which element was the most important. We do believe that how the learner is situated relative to authority is a major factor.[6]

Summary

On one level, the use of language in class, homework assignments and project descriptions that mirrors an authentic situation also reinforces confidence and ability in problem solving. The absence of such language reinforces situating the learner as *student*--- a subtle but important difference. On a deeper level, the nature of knowledge construction in a social context is important[7]. The emergence of a problem solution requires interaction and externalization through language and visualization. The quality of the solution derives directly from the nature of the interaction. We will discuss this issue and the dynamics of intellectual development in the sophomore year, including the limits to students' cognitive growth. These limits appear in even the best of students and suggest that situated learning does have boundaries, though they may be hard to define.

The methodology described above requires four major steps: 1. design of the student exercise (the engineering problem that must be solved); 2. implementation (including taping) of the competition or student "performance"; 3. transcription of the performance; and 4. detailed review of the transcripts and videotapes. It is time-consuming and potentially expensive compared to more traditional or less direct methods (like in-class exams or surveys). A multidisciplinary team, preferably with a gender mix, is really needed for step 4. At least one member should have professional training in behavioral analysis of videotape data. Despite these apparent limitations the depth and richness of the data are well worth the efforts. The ability to probe student learning and behavior while they are engaging disciplinary material is a great advantage compared to many other methods. The next challenge is to use the results to improve the learning process.

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