Feedback in Complex, Authentic, Industrially Situated Engineering Projects using Episodes as a Discourse Analysis Framework – Year 1

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Introduction

Over the last seven years, we have developed, implemented, and studied student learning in cyber-enabled learning systems.[1,2] Central to each of these learning systems is a virtual reactor that enables a team of students to develop, test, and refine solutions as they are tasked with developing an optimal "recipe" for one of two virtual reactors. The two virtual reactors include: the Virtual Chemical Vapor Deposition (VCVD) Reactor, a simulation of an industrial-scale chemical vapor deposition (CVD) reactor, and the Virtual Bio Reactor (VBioR), based on an industrial scale bioreactor process. These learning systems provide students a capstone experience in which they can apply experimental design in a context similar to that of a practicing engineer.

Throughout students' engagement with a learning system, student teams meet with an instructor, called the coach. The student-coach interactions are different from those in traditional classroom settings. Students and a coach interact in semi-structured design meetings, called coaching sessions, which mirror the structure of industrial design reviews. Students take on the role of process development engineers while the coach acts as mentor and manager. We have learned that feedback provided by the coach during these interactions is critical to the success of the learning systems.[3] For effective implementation of these learning systems at other institutions, there is a need to describe the characteristics of successful feedback and the effects of that feedback on student learning. This poster will present the initial findings of the investigation into the nature of the feedback provided by the coach to the student teams and the relationship of that feedback to the strategies students apply as they engage in the task, the models they develop, and their knowledge integration of material from previous courses. Specifically, the research questions for this stage of the study are:

1. What are the different types of feedback coaches provide and what characteristics distinguish the different types of feedback?
2. What is the relationship between coach feedback and the development of the experimental models and strategies students apply as they work to complete the assigned task?

Feedback

Feedback is an essential tool used by instructors to close the gap between current performance and desired performance. In education, it takes many forms, including interactions both inside and outside the classroom. Feedback inside the classroom has been found to have a strong connection to student performance and learning.[4] Additionally, the importance of office hours has been identified and educators have looked for ways to improve effectiveness.[5,6] Student-faculty informal interactions, often including feedback, have been correlated with many factors shown to affect learning.[7]

According to a meta-analysis by Hattie and Timperely, the effect size of feedback is among the highest of all educational factors, weighted heavier than such factors as students' prior cognitive ability, socioeconomic status, and reduction in class size.[8] They describe feedback as a process where teachers make learning goals clear to students, help students ascertain where they are relative to those goals, and then assist students in moving their progress forward. However, there is no general consensus as to what specific attributes of feedback lead to improved learning, and multiple lines of research emphasize that appropriate feedback is specific to the learning context of the student and/or task.[9] Researchers have advocated that feedback works best when it directs student attention to appropriate goals and actions,[10] and encourages student reflection.[11] Others believe that students are most receptive to feedback when they are sure their answer is correct, only to learn later that it was wrong.[12] Additional factors include a student's understanding of and agreement with the feedback provided, the motivation the feedback provides, and the limits on the student's cognitive load.[13]

While feedback has been shown to strongly influence student performance and learning, explicit research on the effect of feedback in engineering education is sparse. We have performed a literature search of the major engineering education journals (e.g., *Journal of Engineering Education*, *Advances in Engineering Education, International Journal of Engineering Education*) and conference proceedings (e.g., ASEE, Frontiers in Education, Research in Engineering Education Symposium) and found only a few papers specifically addressing feedback. Authors of a study of first year engineering students at Pennsylvania State University "suggest that faculty interacting with and providing constructive feedback to students was significantly and positively related to student gains in several engineering design and professional skills."[14] This result is consistent with studies in other disciplines.[15] Moreno et al.[16] examined the role of computer-automated feedback in a computer-enabled learning system in a 1st-year electrical engineering class. They compared the effects of different types of feedback on student learning for worked-example instruction based on well-constrained electrical circuit problems. The authors found positive effects by gradually removing scaffolding and by promoting metacognition (thinking about thinking) during problem solving. In the proposed research study, we seek to add to the knowledge base of the effectiveness of feedback in engineering education.

Instructional Design

The instructional design is intended to provide an authentic environment where the ability to learn is coupled with the ability to use knowledge in a practical context. The task is posed in the same context as that which engineers would encounter in practice. Teams of students are asked to take the role of process development engineers and optimize the performance of a set of reactors based on experimentation. In completing the task, students engage in iterative experimental design as they seek to find the optimum parameters for the engineering process by changing input parameters and examining output measurements. To better reflect the behavior in real reactors, random process and measurement variation and systematic variation are added to the data from the simulation output that students analyze. Simulating the physical operation of the process and metrology equipment, greatly simplifies the act of performing experiments. Therefore, it allows a student to experience a different emphasis on the experimental design process than he/she typically encounters in a physical laboratory. In this way, the Virtual CVD Reactor provides the instructor a tool to scaffold cognitive demand and afford the students an opportunity to more closely follow the iterative process of experimental design that is used by professionals in practice.[1,2]

The instructional activities are constructed around principles of scaffolding, coaching, reflection, articulation, and exploration.[17] A summary of activities for the student teams is shown in Table 1 together with the appropriate instructor- student interactions. The shaded activities form the focus of this study. The project is introduced in 2-3 lecture periods, where the instructor presents the project task, the framework for the project, general technical background about the industrial context and some of the relevant engineering science, and the project deliverables and timeline. At this time, the students are also provided a design notebook and asked to record activity, keeping track of the run parameters, data analysis, interpretation, and conclusions and decisions from the interpretation. This reflective activity is intended to help the student teams formulate analysis and design strategies. As such, the notebook becomes an artifact with which the team interacts to produce learning.

Table 1: The timeline of the *Industrially Situated Virtual Laboratory Project*

Timeline	**Key Elements**	**Instructor-Student Interaction**
Project Introduction	• Goals of the task are introduced • Criteria for success are indicated	Instructor delivers a presentation introducing integrated circuit manufacturing, some engineering science background, the virtual CVD software interface, and presents the objectives for the task and the deliverables.

End of Week 1	• Design Meeting (DM)
	  ○ Initial run parameters
	  ○ Experimental strategy
		Student teams meet with the instructor to discuss their design strategy. If initial parameters and strategy are acceptable, the instructor provides students with username and password to access the Virtual CVD laboratory.

End of Week 2	• Update Meeting (TUM) ○ Progress to date	Student teams meet with the instructor to discuss progress to date, any issues they may have, and the direction they are going.
End of Week 3	• Final Recipe • Final Report • Final Oral Presentation • Design Notebook	Teams deliver a 10-15 minute oral presentation to the instructor, two other faculty members, and the other students in the laboratory section. The presentation is followed by a 10-15 minute question and answer session.

Next, the student team develops its initial design strategy. This element directs students to an information gathering/problem scoping phase that places unusual responsibility on the students themselves to formulate the problem. This formulation evolves during a 20-30-minute *Design Meeting* (DM) through discourse between the student team and a faculty instructor, the domain expert, who acts in the role of manager and mentor. In providing feedback, the instructor reinforces the epistemic frame of the engineering profession by modeling the way an engineer thinks and acts.[18] At this meeting, the students must deliver a memorandum that specifies the parameters for their first run, a strategy for subsequent runs, the approach to evaluate the experimental data from the runs, and a virtual budget for the entire project. In developing their initial design strategy, students both search the literature to obtain reasonable reactor parameters and integrate prior knowledge from a diverse set of courses ranging from material balances and reaction kinetics to applied statistics and experimental design. During the meeting, the instructor provides feedback by asking questions that guide the students in developing features of their strategy, initial parameters, and budget that they have not appropriately addressed. The instructor feedback is carefully calibrated to engage the students in identifying the gaps in their current design and to direct their thinking on how they can address those gaps rather than simply correcting errors in the students' approach. The team must have its design approved (typically after a revision) before they are allowed to run experiments in the virtual laboratory.

The team then undergoes the process of iterative experimental design by planning experiments, analyzing data, developing models, and identifying strategies. This process is punctuated by a *Team Update Meeting* (TUM) with the team and the instructor, which has a similar structure to the first meeting. Finally, the team submits a process recipe (or multiple recipes for multiple reactors) for release to high volume manufacturing and presents an oral and written report. After the ten-minute oral presentation, an interactive questioning process between the team and the instructors and the other members of the class provides the final opportunity for students to synthesize their understanding.

Methods

Setting: The participants in this study are students and instructors associated with a chemical, biological and environmental engineering program at a large, public research university. The virtual laboratory project is one of three projects student teams complete in their capstone laboratory class. They can choose between the VBioR Laboratory and the VCVD Laboratory. The course also includes two physical laboratory projects. Therefore, during the 10-week quarter, there are three distinct laboratory projects including (1) double-pipe heat exchanger, (2) ion exchange chromatography, and (3) VBioR/VCVD. Bioengineering and environmental engineering students typically choose the VBioR Laboratory Project, while chemical engineering students have the option to choose either the VBioR or VCVD Laboratory Project.
Through this class, approximately 80-120 students participate in the Virtual Laboratory Project each year. The students work on the project as part of a small student team, typically consisting of three students. Approximately half of the student teams choose the VBioR Laboratory Project. Students are asked if they are willing to participate in the research study through an informed consent process. Each year two instructors also participate in the study by engaging the student teams in feedback processes during the project.

Data Sources: Three different types of data have been collected in year 1 of the project:

1. Individual Student Perception of the first coaching session
2. Video recordings of the coaching sessions
3. Ethnographic participant observation during the entire project

1. Individual Student Perception of the first coaching session:
With constructivism as the theory of learning for this study, student perspectives on the feedback process are a necessary component of this analysis. Students were asked to individually reflect on the first coaching session by responding to the following questions:

1. What are the top three things you are taking away from this meeting?
2. What interaction with your supervisor do you remember most and why?
3. Is there anything that happened during the meeting that
    a. especially helped you understand something?
    and/or
    b. was especially confusing and you wanted to discuss more?

Student answers to these reflection questions were hand written and returned to the instructor. Responses were received from 104 students. Student responses to the above questions provide insights regarding student perceptions of feedback from the DMM. Since the reflections are labeled by team number (though not by individual student), the student perceptions can be associated to specific element of the recorded meeting. In analyzing these data, it should be kept in mind that the responses could be more favorable than if the data were collected anonymously.

2. Video recordings of the coaching sessions
The coaching sessions where the teams and the instructor interacted were video recorded for both VCVD and VBioR projects. These meetings occurred with different coaches in different locations, but the video strategy was identical. The (usually) four participants sat at a round table during the meeting and two video cameras were used, one pointed at the team and the other pointed at the coach. In total 28 teams were video recorded, 14 from each virtual lab project. Recordings included the initial design meeting (20-30 min), a follow-up design meeting for 25 teams (generally brief), the update meeting (15-30 min), and the final presentation (20-30 min). Therefore, there is over 1 hour of data for each team. Student work products, including their written memoranda for the meetings, their design notebooks, final written and oral reports, and records of experimentation from the database were also collected.

3. Ethnographic participant observation during the entire project
A subset of three teams (two VCVD and one VBioR) was observed and audio/video recorded throughout their completion of the project. This data source provides a finer grained analysis of how a subset of the teams responded to the feedback in the coaching sessions.

Preliminary Results

So far we have analyzed student perception of the coaching sessions for the individuals who completed the VBioR Project (n = 44). This assessment of student perceptions of feedback comes from responses from students asked to reflect on the feedback they experienced during the Design Meeting. In most cases, the team members' responses to the first question tend to be similar, while responses to the other questions are more varied. In the second and third questions, the students noted several instructor techniques that they found helpful for increasing their understanding. These instructor techniques include situating in engineering practice, drawing graphs, doing calculations, advising on literature/research, relating the project to known concepts, and asking questions.

Using the themes developed for episode discourse analysis,[19] the most frequently cited themes by question are shown in **Table** . The threshold frequency for inclusion in the table is five. Kinetics is the most common theme for all of the questions, with a total frequency of 85. Experimental Design (65), Transport (33), Budget (25), and Measurement Strategy (16) are also frequently cited.

Table 2 - Most frequent themes in student reflection responses by question

Question	Most Frequent Themes (frequency)
Q1: What are the top three things you are taking away from this meeting?	Kinetics (28), Experimental Design (29), Budget (18), Measurement Strategy (11), Transport (10)
Q2: What interaction with the professor do you remember most and why?	Kinetics (22), Experimental Design (17), Transport (9)
Q3a: Is there anything that happened during the meeting that especially helped you understand something?	Kinetics (27), Transport (13), Experimental Design (15)
Q3b: Is there anything that happened during the meeting that was especially confusing and you wanted to discuss more?	Kinetics (8)

In general, six common instructor techniques were highlighted by student comments, including (1) situating, (2) drawing, (3) calculating, (4) literature/research, (5) relating, and (6) asking. These techniques align with the Feedback Theory associated with this study. Nearly all of the student responses point to feedback that is specific to the task at hand – the VBioR Laboratory Project. The asking technique is related to using facilitative feedback. Several students noted a preference for more facilitative feedback in response to open-ended questions regarding what about the DMM was memorable and especially helpful.

Planned Analysis

We use an episodes framework that we have developed to examine the characteristics of feedback during the coaching sessions.[19] Each episode is defined by the content that is addressed (e.g., reaction kinetics), called the episode theme. Each theme is composed of up to four stages: surveying, probing, guiding, and confirmation. A coaching session typically contains approximately 10-20 episodes. In addition, we use a method called Model Maps to represent student groups' model development as they complete the task.[20] Model Maps are used to identify teams' models and strategies and are interpreted in terms of the guidance the team received during the coaching sessions. The differences noted before and after coaching sessions are interpreted with reference to the episodes analysis.

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