AC 2011-1434: EPISODES AS A DISCOURSE ANALYSIS FRAMEWORK TO EXAMINE FEEDBACK IN AN INDUSTRIALLY SITUATED VIRTUAL LABORATORY PROJECT

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Episodes as a Discourse Analysis Framework to Examine Feedback in an Industrially Situated Virtual Laboratory Project

Introduction

Feedback has been shown to be one of the most important tools used by faculty to help students close the gap between actual and desired performance. Additionally authentic, situated environments are believed to benefit student learning. Studies of feedback in situated projects are uncommon and needed. This study proposes the use of *episodes* as a discourse analysis framework to investigate feedback in an industrially situated virtual laboratory project. While episodes have been used in other disciplines, they present a new framework for engineering education research.

This paper focuses on a case study of feedback provided to four teams of students as part of an open-ended senior project. The 12 students are drawn from two cohorts in their final year of their undergraduate studies in chemical, biological or environmental engineering at a large public university. Students were organized in teams and placed in the role of semiconductor process engineers, tasked with optimizing a virtual chemical vapor deposition reactor through experimentation, analysis, and iteration. This three week project involved two structured meetings with the instructor who acted in the role of an expert consultant. These meetings are referred to as coaching sessions. The first coaching session for each team is explored in this paper. In that coaching session, termed the *design memo meeting* (DMM), students present their experimental design strategy in hopes of being granted permission to begin experiments. This study is part a larger investigation on student learning in virtual laboratories.

We posit that the presented project is industrially situated and perceived as authentic by students. In this learning environment, the nature of student-instructor interactions is distinctly different than in traditional classroom settings. Feedback during the coaching sessions is intentioned, critical, and catalyzes student learning. Using episodes, the nature of feedback to four different student teams during the DMM is compared. Finally, we argue that the episodes framework provides a potential scaffolding tool for instructors to more effectively provide feedback in this type of learning environment.

Theoretical Framework

Feedback

Feedback is an essential tool used by instructors to close the gap between current performance and desired performance. Feedback in the academic world takes many forms, from interaction in the classroom to interaction during office hours with a teaching assistant or a professor. According to a meta-analysis by Hattie and Timperely, the effect size of feedback is among the top of all educational factors, weighted heavier than such factors as student's prior cognitive ability, socio economic status, and reduction in class size.[1] They describe feedback as a process where teachers identify specific learning goals, help student ascertain where they are relative to reaching those goals, and then assist students in moving their progress forward. Feedback inside the classroom has been found to have a strong connection to student performance.[2] Results, from a study of over 1,500 first year engineering students, "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."[3] Similar findings are echoed by others.[4,5] Faculty-student interaction outside of the classroom also often includes feedback. Some studies have targeted improving professor effectiveness in office hours,[6,7] while others cite the importance of office hours as an instructional tool from both the faculty and student perspective.[8,9,10] Student-faculty informal interactions, often including feedback, have been correlated with factors shown to affect learning, such as socialization, academic achievement, satisfaction with college, intellectual and personal development, persistence and attrition, career and educational aspiration, as well as many other concepts.[11] Feedback greatly impacts student learning and performance.

One important aspect of effective feedback is the degree to which it is tailored to individual students. Several models attempting to describe such student dependent instructional techniques have been posed. *Student-centered instruction* describes instructional methods that encourage student learning in individual and small group settings. This is accomplished by instructor coaching on such skills.[12] *Individualized instruction* is characterized by flexible assessment with continuous feedback, students taking an active role in the instructional process, and variation of instructional methods based on individual student abilities and performance.[13] *Dynamic assessment*, another form of tailored feedback, is defined as focusing on student improvements in the cognitive processes related to problem solving by using an assess-intervene-assess instructional framework.[14] Finally, one of the clearest models of tailored instructional methods comes from the literature on K-12 education. *Differentiated Instruction* is explained by C. A. Tomlinson:

> "In differentiated classrooms, teachers provide specific ways for each individual to learn as deeply as possible and as quickly as possible, without assuming one student's road map for learning is identical to anyone else's"[15]

Regardless of the subtle differences in structure of the models listed above, review of the literature clearly points to a consensus in the education community; when instructional methods, including assessment and feedback, can be constructed to address individual student needs, learning increases.

Authentic, Industrially Situated Learning

Learning has also been shown to increase when students engage in authentic projects. The advantages of authentic, situated learning environments have been described by several researchers, some of which are highlighted in the NRC report *How People Learn*,[16] and are interpreted relative to engineering by Prince and Felder:[17]

- New learning involves transfer of information based on previous learning
- Motivation to learn affects the amount of time students are willing to devote to learning. Learners are more motivated when they can see the usefulness of what they are learning and when they can use it to do something that has an impact on others.
- The likelihood that knowledge and skills acquired in and academic setting will transfer to real work settings is a function of the similarity of the two environments.
- Helping students develop metacognition – knowledge of how they learn – improves the likelihood of their transferring information learned in one context to another one.

Industrially situated problems are real with monetary implications and more severe consequences than that of a wrong answer on a contrived test or homework problem. Taken in the context of the report above, there exist several clear benefits of authentic, situated environments for student learning. First, students can potentially increase transfer due to similarities between aspects of the educational project and an industrial project. Second, students may value a situated, authentic project more highly than traditional coursework and thus be more motivated and more willing to invest time and effort into learning.

Establishing and validating authenticity in feedback during such projects is difficult. Feedback in engineering practice is an area in which little research currently exists. In fact, engineering practice itself is an area in which little empirical research exists.[18]

Episodes

This study uses episodes as a framework to examining feedback, especially in the form of the coaching sessions in the situated project. Episodes have been used as a framework for discourse analysis in other educational settings.[19,20,21] The term "episodes" has been used to describe entire situations, such as an entire class period, as well as smaller subsets of discourse. T. A. van Dijk present a broad description of episodes as follows:

> "In this sense an episode is first of all conceived of as a part of a whole, having a beginning and an end, and hence defined in temporal terms. Next, both the part and the whole mostly involve sequences of events or actions. And finally, the episode should somehow be 'unified' and have some relative independence: we can identify it and distinguish it from other episodes." [22]

Mannila et al. described episodes as requiring a "collection of events that occur relatively close to each other in a given partial order."[23]

Research Design

Participants

This paper focuses on a case study of four teams, a subset of a larger investigation on student learning in virtual laboratories. All students were undergraduates in their 4th or 5th year in a chemical, biological or environmental engineering program and were enrolled in the capstone laboratory course. The four teams studied were self-selected, maintained for the entire course, and comprised of three students each. The teams studied consisted of a total of eight female students and four male students. Two teams each were selected from consecutive years. Approximately 80 students were enrolled in the capstone course each year.

The process for choosing teams to participate in think aloud protocol study addressed several factors, the most fundamental of which was simply schedule; teams were only chosen if a researcher was available during the team's laboratory section and projected work times. Furthermore, gender distribution also contributed. During the selection of the cohorts presented in this paper, a preference was given to mixed gender teams or all female teams since other alternative gender distributions had been studied previously. The perceived willingness of a team to participate was also a contributing factor to team selection. This includes perceived willingness for both informing the researcher of all team meetings as well as verbalizing thoughts during meetings. A team's perceived willingness was a major criteria for selection because of the limited window of data collection associated with the virtual laboratory project. It should be noted that students' academic performance (e.g. GPA, class standing, test scores) was not a contributing factor to team selection. Also, more than half of the students had previous experience in engineering internships or laboratory research positions.

The faculty member studied in this paper has many years of thin films processing domain experience and has developed several different courses on the subject. This faculty member has performed the role of coach in the virtual laboratory project in this capstone course for several years and has coached multiple teams as they have worked on the project.

Setting and Instructional Design

This paper concentrates on work at a research and degree granting public university located in the Northwest U.S. The 10-week capstone course featured the virtual laboratory project as the second of its three laboratory projects; the other two laboratory projects were traditional physical laboratories. Students had three weeks to complete each laboratory project. During the virtual laboratory portion of the course, students chose between the Virtual BioReactor (VBioR) laboratory and the Virtual Chemical Vapor Deposition (VCVD) laboratory. Students studied in this paper chose the VCVD laboratory as their virtual laboratory project.

The VCVD laboratory was developed to afford students the opportunity to:[24]

(1) Promote development of schematic and strategic knowledge[25] in a way that applies core concepts from the curriculum.
(2) Engage students in an iterative experimental design approach that is reflective of the approach used by practicing engineers.
(3) Provide an authentic context, reflective of the real-life working environment of a practicing engineer, such as working with a team to complete complicated tasks.
(4) Promote a learner-centered approach to an open-ended design problem which results in an increase in the student's tolerance for ambiguity.

From an instructional design standpoint, the VCVD laboratory project is very open-ended. Laboratory experiences earlier in the curriculum are often prescribed with clearly defined operating procedures. Strategy in these typical physical laboratory experiences is focused more on how to finish earlier or how to troubleshoot malfunctioning equipment within tight time constraints. In the VCVD laboratory students are required to accomplish an authentic task (maximize reactor performance) with very little procedural or strategic information provided. This increase in cognitive demand in the strategic domain is facilitated by a decrease in demand in the haptic domain. Instead of spending time and cognitive resource setting up equipment and ensuring functionality of instrumentation for a limited experiment, students are able to use the resources previously dedicated to these types of actions on other activities. Students must manage a budget, create and carefully plan the project strategy, and analyze and assimilate the information from multiple experiments that were easily run; the process of running the reactor once, measuring selected wafers, and exporting the measurement data to excel takes approximately 3 minutes.

The Virtual Chemical Vapor Deposition Project:
The VCVD laboratory project tasks students with the engineering objective of developing an optimal process "recipe" for a low pressure chemical vapor deposition reactor. The project is intended to be situated in the context of the integrated circuits (IC) industry with the reactor being one step of a multi-step process in high volume IC manufacturing. Optimization includes both the uniformity of the deposited silicon nitride (Si_3N_4) film, as well as utilization of the reactant gas while minimizing development cost. Students are charged $5,000 per run and $75 per measurement point. There exists an abundance of literature on low pressure chemical vapor deposition of silicon nitride; however, while general strategies from one reactor can be applied to another reactor, the parameters for optimization are reactor dependent, thus providing a genuine as well as unique challenge. Students are also required to keep a detailed laboratory notebook, similar to those kept in industry, which should contain observations, strategies, analysis, results and logic. This virtual lab is comprised of a 3-D interface available on school computer laboratory computers or for download and installation to a student's personal computer. Similar in form to the virtual space in many current video games, the students navigate through a virtual 3-D clean room in a microelectronics factory. In order to optimize the process, the students control nine process parameters: reaction time, reactor pressure, flow rate of ammonia, flow rate of dichlorosilane (DCS), and the temperature in five zones in the reactor. After entering and submitting parameters to run, students may implement their measurement strategy in which they choose the number and position of wafers to measure, as well as the number and position of points within each wafer. The results of measurements can be viewed in the program or exported to an excel file where further analysis can take place. Behind the interface, a first principles mathematical model generates the data provided by the virtual reactor. However, the instructor can add measurement and process error so that no two runs or measurements give the same value. More information regarding the VCVD laboratory is available elsewhere.[26]

At the beginning of the VCVD laboratory project, the instructor introduces the faculty member who serves as coach (subject matter expert). The coach presents background technical information, introduces the VCVD laboratory software and presents the project objectives during two, 50 minute class periods. A timeline, list of deliverables, and associated coach-student interaction are shown in Table 1.

Table 1. The timeline of the VCVD project.

Timeline	Deliverables	Coach-Student Interaction
Project Introduction		Coach 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 Memo Meeting (DMM) o Initial run parameters o Experimental strategy	Student teams meet with the coach to discuss their design strategy. If initial parameters and strategy are acceptable, the coach provides students with username and password to access the Virtual CVD laboratory.
End of Week 2	• Update Memo Meeting o Progress to date	Student teams meet with the coach 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 • Laboratory Notebook	Teams deliver a 10-15 minute oral presentation to the coach, 2 other faculty members, and the other students in the laboratory section. The presentation is followed by a 10-15 minute question and answer session.

The Design Memo Meeting (DMM)
The DMM, the first of the coaching sessions, occurs at the end of week one of the project. At this time, the students are asked to propose the first set of experimental run parameters and measurement locations as well as summarize their experimental strategy. This information is presented to the coach in a design memorandum. Logistically, the students bring the memo to a scheduled, 30-minute meeting with the coach, who performs the role of the project supervisor. Usually the meetings utilize the entire allotted time. Additional time is available for students needing more coaching, usually per student request. Once the students have completed the design memo and DMM satisfactorily, access to the 3-D VCVD laboratory interface is granted and they can begin experimentation.

The coaching sessions provide an early checkpoint for the student teams. This early checkpoint prompts students to stay on task regarding the VCVD project, which, as reported by students, is one of the most time demanding projects that they experience in the undergraduate program. Further reinforcing student preparation is the institutional awareness regarding the challenging nature of feedback in these coaching sessions which, among other goals, is intended to promote student preparation for the interaction. This feedback is not intended to "give the students answers" but rather to guide them toward a more desirable solution by the coach asking difficult and thought-provoking questions regarding the key aspects of the project. The early intervention also allows for this challenging, tailored feedback to occur at an early stage in the process affording the students two opportunities to apply feedback given by the coach to a final assessed product (the final report and presentation). Because the feedback is tailored for each student team, it is expected that content, flow and effect of each coaching session would be unique.

Like the project as a whole, the coaching sessions are situated in an industrial setting. Students are told to prepare as if they were presenting to their project supervisor and the coach maintains this role as much as possible while attending to the educational objectives. Additionally, while the students are given a degree of structure regarding what the meeting entails, such as the core requirements for the memo, they are not given a detailed set of requirements, such as memo format and exact structure of the meeting. The meetings instead have the feel of "show your boss what you have been working on." In this way the meetings are scaffolding the students towards what may be expected of them in workplace meetings.

Methods

Data Collection
Data sources for this study include think aloud protocol, semi-structured audio-recorded interviews, and student work products. Think aloud protocol consists of audio recordings of teams as they "think aloud" as they complete the project. These data are supplemented by observation notes from a researcher. Audio recordings are transcribed and the transcripts are used for analysis. Semi-structured interviews with six of the twelve participants have been conducted. A set of interview questions was initially created by the researchers and additional questions were added on a case by case basis. A variety of questions was asked ranging from open-ended questions such as "can you walk me through the project?" to more specific questions such as "what do you think the role of the instructor was in the design memo meeting?" Interviews were conducted 6-9 months after the students had completed the project. Interviews were also audio-recorded and transcribed.

A complete think aloud transcript for one team is 100-200 pages in length. For this study, we primarily focus on the DMM which is 5-10 pages. Two researchers began phrase-by-phrase and word-by-word coding with the goal of connecting teacher objectives to student goals. After reading the four DMM transcripts, it was observed that each DMM followed a similar pattern. Not only were common topics brought up, but there was also a similar pattern in each topic discussion. This pattern was then defined, documented, and revised. The pattern was member checked with the coach and agreed upon by the research team, and defines the episodes framework presented below. Then, two researchers coded the four coaching session transcripts individually, using this framework. They labeled episode components within the transcripts and identified the key topics of each episode. Throughout the coding process, the researchers consulted with each other and the research team regarding less clear sections of discourse. After coding, the researchers compared coded transcripts. During this collaboration, major episode topics were agreed upon almost unanimously. Less critical elements such as the distinction between some of the episode components were not agreed upon unanimously but to a degree that allowed for consensus in all cases.

Results and Discussion

The results and discussion is presented in four sections. First, we report results of student interviews regarding the student perception of the DMM, specifically focusing on the student perception of authenticity and effectiveness. While the intent is to provide an experience that is industrially situated, it is important to validate from the student perspective. Second, the framework of episodes to characterize the student-instructor interactions during the DMM is described. Episodes provided a structure for analysis of discourse and are helping direct ongoing research. Preliminary research results that demonstrate the use of episodes as an analysis tool are presented next. These results are interpreted in terms of the effectiveness of the project and the DMM. Finally, the use of episodes as a tool for instructional scaffolding is briefly discussed.

Student perceptions of the DMM:

Analysis of the student interviews provides some insight into the student perception of the DMM. Follows are some of the common themes among the 6 students interviewed along with student quotes supporting those themes.

- The majority of students expressed that coaching sessions were similar to either their expectation of or experience in industry meetings with a mentor or boss; some students even contrasted this project interaction with typical student-faculty interaction.
  "when it turned into more of like the group meetings [DMM and Update MM], I felt that he was more there in the position of someone like a manager that was like questions like 'what are you doing? Why are you doing this?' and instead of telling us ' here's the process this is great' I found it more helpful 'cause it kind of made us think more about what was going on because he wasn't telling us directly what we needed to do but instead bringing up more questions for us, and more problems to solve."
- All students interviewed found the DMM beneficial to the project.
  "Those meetings gave us direction, he would mention things that we had forgotten and stuff like that, with his way of asking questions about stuff we said."
  "just getting [coach]'s feedback was beneficial. Finding out like if what we came up with on our own was a good idea or if we missed something."

- Students expressed that they appreciated the coach asking difficult questions.
  "I personally like it when [the coach] asks questions that we really don't know the answer to and um cause it really helps us think more about what is going on in the process. I mean it is frustrating while we are there and we look really ridiculous being like 'I don't know' but overall I find that more helpful than being there and just listening and then excusing us to go."
- The students most often identified the coach's primary role as making sure they were on the right track and guiding them toward a better solution. During this process, students recognized that the coach withholds information and accept this as part of learning. Interwoven in such responses is an implicit recognition of the value of leading students to their own knowledge integration.
  "I think his role is…to help you get to a place where you can be successful and not be stuck somewhere in your project and help you do that without straight up telling you, helping you realize it."
  "He will lead you to the answer; he won't ever tell you the answer. It usually ends up being something that you already know…And if you come to the idea then he'll let you know that you got there. But I don't know, it's always annoying at the time but you look back and you're like, that was actually pretty helpful."

It should be noted that these are not all themes present in interviews; some of the other themes include that the project took too much time, stress, approaches to problems, team dynamics, students liked open-endedness, as well as other themes. The themes presented with quotes above have been echoed in interviews of students not analyzed for this paper and continue to be representative of student interviews. Students, many of which have had internships and research laboratory experiences, expressed that they perceive the DMM as representative of an industrial setting and beneficial student-faculty interaction in providing feedback through asking questions, without providing too much information.

Episodes Description and Development

An episodes framework to reflect student-coach (instructor) dialog in the DMM is shown in Figure 1. The description of each episode component, along with an example, is given in Table 2. In the Surveying stage, the coach in the DMM surveys the student team's understanding by reading the memo and then asking broad questions or simply letting students explain their approach to the project. During this time, the coach attempts to identify potential problem areas in the team's core knowledge or design strategy. Identification of potential issues leads to the Probing stage where the coach asks probing questions regarding the potential issue in order to assess if it was indeed a problem. The Guiding stage where the coach attempts to guide the students toward a more favorable approach occurs if the coach assesses that a problem is present. Finally, in the Confirmation stage confirming statements (often by both coach and students) conclude the episode and then a new episode begins. As indicated in Figure 1, the assessment-heavy and feedback-heavy portions of an episode are identified. The definition of episodes for this work fits the description presented by van Dijk,[19] in that they are topic themed and have a clear beginning and ending. Further, a characteristic noted by Mannila et al.,[20] a structure within episodes stood out in the text.

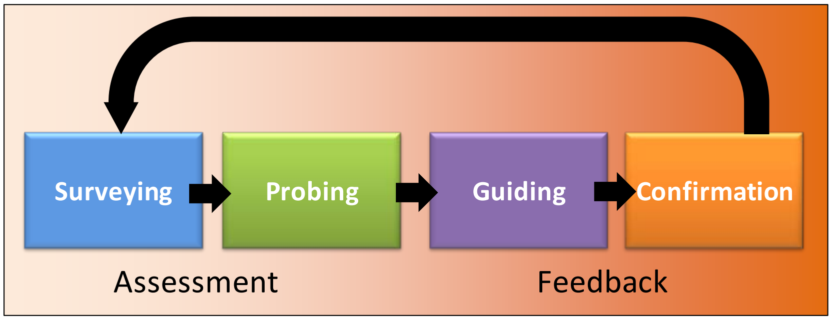

Figure 1. Episode structure with more assessment present in surveying and probing and more feedback in guiding and confirmation components. The process is iterative and all components are not required for each coaching session.

Table 2. Descriptions of each of the four parts of episodes. C denotes the coach and S1, S2, and S3 the students.

Episode Stage	Description	Example episode on "intra-group validation" and "situate"
Surveying	This component consists of the instructor becoming familiar with the team and their approach. It also includes the instructor trying to identify potential areas for further discussion and probing, areas in which students have misconceptions or incomplete understanding of important concepts. Surveying is based in part and loosely on an unwritten "check-list" of common student design shortcomings.	C: [upon conclusion of mass balance episode] And are you confident of these numbers? S1: Barely S 2: That's just the minimum to get the deposition so that would require 100% utilization on only the wafers. So that doesn't include the reactors.
Probing	In this part the instructor probes the students by asking directed questions on specific concepts to further understand the students' understanding of those concepts and how they will be used and will impact the design strategy.	C: So, S1, you're confident…So does that mean that you did the calculations? S 1: Yes. C: I see. Did you do the calculations (to S2)? S 2: No. C: And S3? S 3: I didn't work it out by hand.
Guiding	The guiding component occurs after the instructor has identified and confirmed a misconception or shortcoming in the students understanding. This part generally consists of the instructor guiding students either to make them aware of aspects that they do not acknowledge or to guide students toward a better understanding of concepts or a more advanced solution strategy. Most of the time guiding occurs through a series of dialogue with the instructor asking leading questions in order to help students discover or recall a more complete understanding of concepts. Occasionally, the answer will be given directly.	C: All right, so this is something where on your homework, or even more so, if you get a method right you get most of the credit, right? S1,2,3: Yes C: On this thing, if you get a method right, do you get most of the credit. No. S1 is generally very accurate. But what else do you think you can do?
Confirmation	During this part, consensus or acknowledgement of understanding occurs between instructor and students. In some cases, a conclusion is stated by the team and verified by the instructor. In others the instructor confirms the student statement followed by a justification or explanation of the episode. In some cases confirmation merely consists of short statements. This component signifies the end of an episode, after which a new topic is brought up and the cycle repeats with another "episode."	S 2: Have everybody check and do it also. C: Yeah, you could have independent checks on that. I mean, you don't want to spend several thousands of dollars to learn that…Oh, I forgot to carry the zero. I'm not saying it's right or wrong, that's just more of a team strategy.

Key characteristics of episodes include the following:

- Each episode is focused on at least one main theme. Episodes can have multiple main themes, for example an episode may be about flow rates but also be explicitly situating, thus serving two purposes.
- Episodes have a beginning and ending point.
- Each episode has a structure consisting of four episode stages (surveying, probing, guiding and confirmation). However, every episode might not include every stage.
- Episodes may be nested within episodes, for instance an episode on density may be contained within an episode on material balance.

Episodes as a Discourse Analysis Tool

Episodes provide an interesting perspective in the analysis of the DMM. Episodes facilitate the relatively quick and easy parsing and subsequent identification of central topics. While central topics can be discovered through carefully reading of a complete transcript, the use of the episodes as a framework expedites the process because topic-centered episodes are punctuated by easily identifiable confirmation statements, usually by both the coach and the students. A researcher need only scan the text for these confirmation statements, and then assess the theme of the text between confirmations.

Once a transcript has been analyzed via the episodes framework, coaching sessions may be further analyzed on a multitude of different levels. Multiple coaching sessions of a single team and/or coaching sessions of multiple teams can be compared. As an example, the topic flow from Team A is shown in Figure 2, which can be compared to the topic flows from the other three teams in Appendix 1.

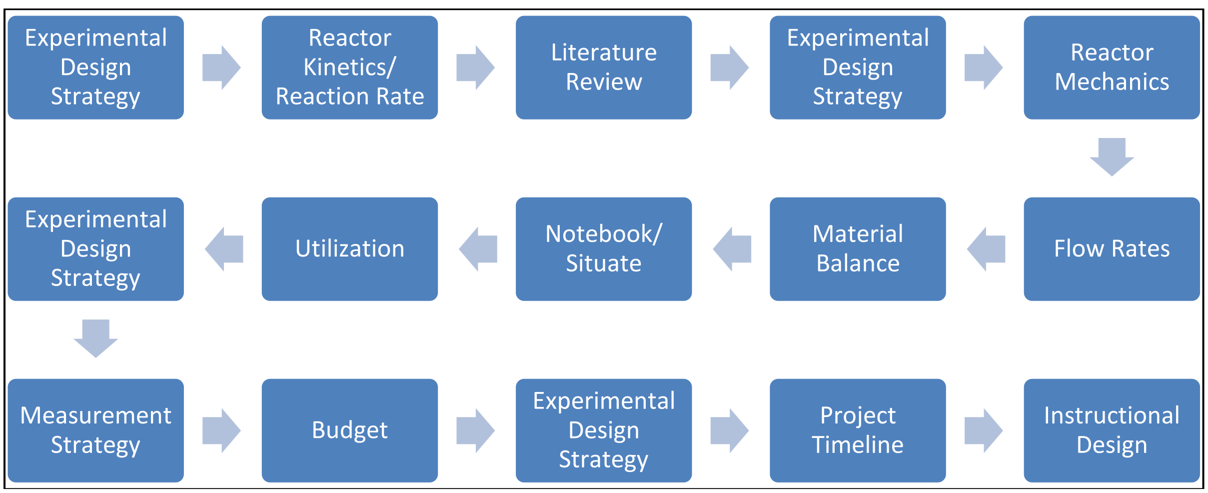

Figure 2. Team A coaching session episode topic flow.

Major topics of the presented coaching session focus around input parameters, core engineering principles and situated themes such as adequate background research, reasonable budget, well justified experimental design strategy, and manufacturing requirements. The episode topics and words/time spent on topics illustrate feedback that responds to the individual needs of each team. Many team attributes factor into the unfolding of the episode flow sequence, including: the team's general preparedness for the meeting (e.g. having a complete memo), understanding and proper application of prior learned concepts, problem solving skills, and team dynamics. An examination of the topic flows shows that there were more episodes on experimental design strategy in Team A's coaching session than in the other teams' sessions. This may be related to the fact that Team A was the top performing team in its cohort and understood many of the episode procedural and conceptual topics that dominated other teams' sessions, leaving more time and energy to be devoted towards strategy. Investigation is needed into detailed examination of topic flows and time spent on topics. In addition, some episodes are nested within other episodes, which are not adequately described with the depiction in Figure 2; for example, a material balance episode is actually contained within the discussion on flow rates.

A single episode around a particular topic can also be used as a starting point for more in-depth data analysis; the topic can be used as a keyword to search through transcripts of team work and student work products before and after the coaching session. In the four teams studied, all four had an episode on material balance. While the topic is the same for all four teams, the episodes look quite different in terms of size, content, depth and the amount of guidance provided. Looking at the episode components for these four episodes on material balance allows for further examination of the nature of these episodes and some of the differences. Summary plots of the word counts in each stage for these four episodes are shown in Figure 3.

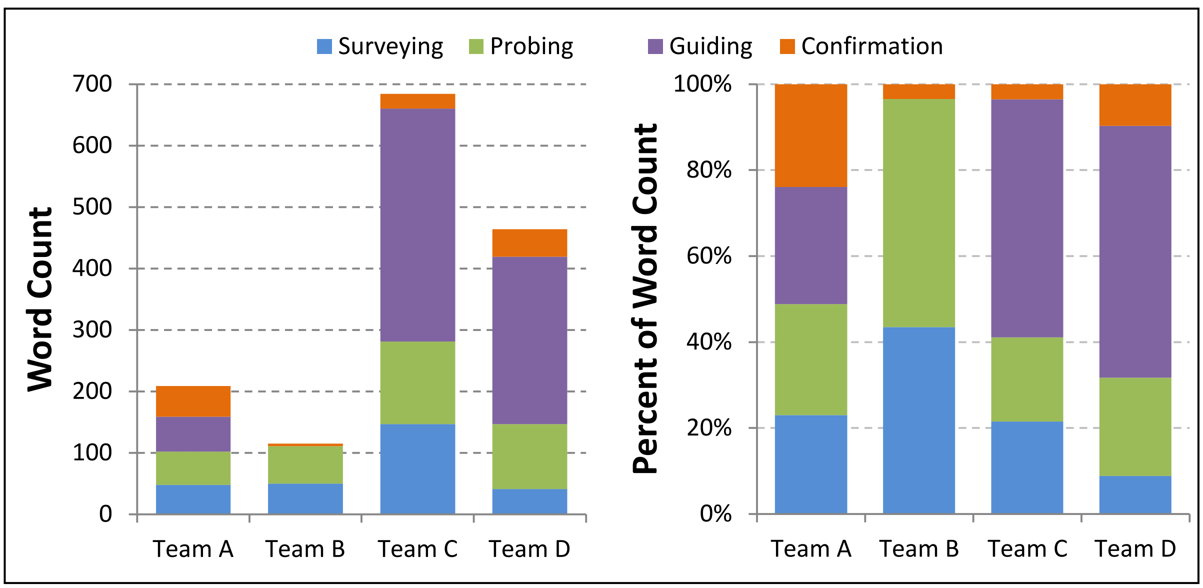

Figure 3. Comparison of Material Balance episodes: (left) word counts for episode components, (right) word count percentages for episode components

Two of the four teams, (Team C and Team D) had not performed a material balance prior to the DMM. The total word count in Figure 3 (left) clearly shows that these two teams discussed the guidance of the topic in greater detail than the other two teams; more than twice as many words were allotted to material balance in the teams that had not previously performed one. This is to be expected as a material balance is an important concept in completion of the project. Next if we consider both word count (Figure 3, left) and the relative break down of component parts (Figure 3, right), Team C and Team D experienced more guiding than Team A and Team B. Not only did they spend more discussion on the topic, but also a larger percentage of discussion consisted of guiding from the coach.

It is interesting to juxtapose the context of the Material Balances episode for the four teams studied. In Team A's Material Balance episode, the episode topic was a concept they had thought of and performed calculations on prior to the DMM, but the DMM reinforced the concept. The episode focused on creating a material balance "chunk" as they had already completed the mechanics of the material balance, but hadn't "chunked" the procedures into one unit. This also plays another role in enculturation, as the term "material balance" is commonly referred to and understood in chemical, biological and environmental engineering. Two comments from a team member interview demonstrate the knowledge integration of the material balance concept through this "chunking" process:

> *"so, learned a lot, learned that the key phrase is, uh what should you do, a material balance, which I'm taking design and it's really true cause like in design it's also like oh just do an energy/material balance and see what you can get from that first"*
>
> *"like I said, like the whole material balance concept that, that's like it's something you learn sophomore year and you don't necessarily really keep in mind as you go through, but it's a really essential element of chemical engineering and just gives you like, makes you step back and think about like the big picture of what's going on"*

Team B had written in their memo that they had done a mass balance and as one might expect, the Material Balance episode is very short (115 words). The coach merely surveyed and probed on calculation verification and the reliability of their reference for parameters. As we can see with the data from Team B, not all episode components are present in all episodes; no guiding was necessary as the students had addressed all of the coach's questions. In some cases, no surveying is directly present because surveying information was gained from previous episodes. Another interesting note, regarding the episode component analysis of Team B, is that the surveying and probing components of this team's material balance episode appear to be surprisingly large as a percent of the total, however if we look at the word count it is similar to that of Team A and Team D. The high percentage is simply a result of the lack of a guiding component and the overall low word count of the episode.

Team C presented a special case, which may illuminate some of the limitations of episodes as an analysis framework. Although episodes were parsed and analyzed, it was more difficult than with the other teams. Episodes for Team C were generally longer than those of the other 3 teams and appeared to have less clear confirmations. The length is demonstrated by a Material Balance episode of 684 words, almost twice as many words as the average of the four Material Balance episodes described and more than 6 times larger than the smallest Material Balance episode described. An interesting question that may warrant further investigation is whether there is a correlation between the effectiveness of episodes as characterized by pre- and post-think aloud data, interview data or survey data and clarity of confirmations or length of episodes. One might, for instance, expect that as episodes got longer with less clear confirmations, that they may also become less effective.

Team D was one of the two that had not performed a material balance prior to the DMM. Their material balance episode was preceded by discussion about modeling diffusion in a complex manner and the flow rate ratio between the two reactants. During the episode, the coach probed regarding the value selection. The team had based their flow rate values on a scientific paper. It becomes clear that the students had not accounted for the difference in size between the reactor in the paper and the reactor with which they would be working. The coach guides them towards using a material balance to assess the reasonableness of their values through leading questions. In addition, the coach promotes the students to reflect on the complexity of their approach and to consider things from a more simple perspective. The students come to the realization that they can calculate the number of moles needed in their final film. Near the end the coach states:
"I really think that you need to do a material balance to see if that is a reasonable number."
The students agree, discuss what values they need for that calculation and the episode ends. In their team meeting after the coaching session, students reflect on the episode as follows:

> *S1: So, I don't know why we didn't think of this, mass balance.*
>
> *S3: I know right? We were thinking yesterday that the whole time, what photo should we use, maybe we should do this, this sounds good [referring to deciding on what they should include in the memo prior to the meeting] and it was like wait, it should be reasonable [referring to the revelation in the meeting]. Nope we can't think about anything. [laughs]…*
> *[pause and other discussion]*
>
> *S3: I am currently working on a material balance and I am trying to go backwards. So I am gonna find the surface area of the wafers, multiply that by 400 because it grows on the inside and the backside of the wafer and then I am going to calculate how much silicon nitride, that comes down to work the chemical equation backwards to see how many moles of dichlorosilane that comes out to. And then factor that into what our flow need to be based on how long we're running this which is 60 minutes. And so that will tell us how many SCCMs we need in order to get this much. And then once I get that flow rate I am going to take that flow rate and say up it by 10% because we're not going to get 100% utilization, especially not on our first run.*

As illustrated by the Material Balance episode, the structure of the coaching sessions allows for effective feedback, specific to each team. Through surveying and probing, instructors assess what competencies and deficiencies a team has relative to knowledge and skills needed to complete the task. As part of this process, students begin to ascertain where they are relative to reaching their goals. Through guiding and confirmation, the instructor then assists them in moving their progress forward. The episodes framework also affords comparisons between coaching sessions on the number and flow of episode topics, depth of specific topics, percent of time or discourse spent on episode components, as well as many other opportunities for analysis.

As the understanding of coaching sessions increases through the use of student interviews and episodes analysis, extending this framework and the information gained beyond research into instructional practice is a logical extension. The next section describes how the episodes framework is of use to instructors using similar situated projects.

Episodes as a Model for Scaffolding Instructor Development

While the topic themed episodes presented in this work provide a framework for analyzing discourse in industrially situated coaching sessions, we propose that scaffolding for instructional improvement is also a useful and powerful extension of this tool. The four part episodes and list of key project components provide a framework that instructors may implement in similar industrially situated learning environments.

Regarding the use of the episodes framework for instructor development, we envision three categories of application. First, and most obviously, this framework may be used by instructors implementing the VCVD curriculum in a similar setting (a senior chemical engineering laboratory course) who also have instructional goals for the project which are aligned with those presented in this paper. This "plug and play" approach may also be useful for instructors who have little time to prepare for the VCVD project or who lack experience or confidence with structuring these types of student/instructor interactions. In this case, the instructor may simply employ the surveying, probing, guiding, and confirmation pattern to investigate and offer feedback on the topics listed in this paper. A list of categorized episode topics for the VCVD laboratory project is presented in Table 3.

Table 3. Common episode topics seen in VCVD coaching sessions. Secondary topics are shown in parentheses.

Chemical engineering content episode topics:	**General episode topics:**
• Material balance • Diffusion (pressure/temperature relationship) • Reaction regime • Reaction kinetics (temperature, concentration) • Modeling of reaction • CVD reactor mechanics • Input parameters (pressure, temperature, flow rates/ratio, time) • Objectives (utilization, uniformity)	• Experimental design strategy(DOE) • Measurement strategy • Budget • Literature review (evaluation of sources, citing sources) • Team dynamics (intra-team validation) • Situate VCVD laboratory (project-class comparison) • Encourage meta-cognition • Notebook

Secondly, this model may be useful for instructors implementing the VCVD curriculum but doing so in order to address instructional objectives that are different than those covered by the episode topics listed in Table 3. In this case, instructors can modify the list shown to develop a new list of topics to be covered using the four part episode framework. During this process two important pieces of information should be considered. First, it should be noted that the list of topics of episodes presented in this paper are based on coaching sessions in the third and fourth year of coaching in this setting (approximately 53 teams). These have been refined based not only on evolving instructional objectives but also on aspects of the project that students have consistently had problems with throughout the years. Furthermore, it should be noted that while an explicit or implicit list of topics is a useful tool to support instructors, the topics and nature of each episode ultimately depend on the team that is being coached. Terms such as "Are there any other questions?" encourage a wide range of topics. Considering these two points, it is important for the instructor to realize that, like the composition of each episode, the episode topics also vary as a function of instructor experience and individual team traits. While a topics list is a useful tool, it is in no way comprehensive in predicting the content of every episode.

Finally, the episode framework may be employed in other situated problem-based learning instructional activities. In this case, the instructor may choose to use the surveying, probing, guiding, and confirmation in coaching sessions in a wide variety of projects. Other industrially situated virtual laboratory projects seeking a framework for instructor/student interactions may find the content of this paper especially easy to apply as the framework was developed in such an atmosphere. However, transfer to more traditional physical projects in the realm of problem-based learning in a variety of contexts may also benefit. For example, one of the authors has recently used this four part coaching episodes framework in memo meetings held with his high school physics students. In this situation, the students were presenting a memo outlining their design for mechanics project in their advanced placement physics class. The project was situated in practice by the students being instructed that they were working as undergraduate interns in a research team attempting to develop a device to deliver fragile cargo (i.e. medical supplies) to high risk areas by air drop. In the memo meeting the instructor served the role of the students' mentor. He used the episodes framework accompanied by reading their memo to survey what they knew regarding the project and look to identify any problem areas. Once a possible lack of understanding was identified, he further probed on the topic in order to fully understand the students' misconception. Next, he guided students' towards a fuller understanding and finally confirmed with the students that they were on the right track. Topics of these episodes were based primarily on elements he deemed essential to the project and secondarily on issues that arose during the meeting. While both the situated, ill-defined nature of the project was similar to the VCVD lab as well as the student's preparation of a memo, many aspects of the project were different. The students were high school seniors, the project involved content focused on mechanics and dynamics, the meetings were substantially shorter (five minutes), and the project in general was much smaller in scope. However, the framework used did provide the instructor (a first year HS teacher) the scaffolding needed to feel confident and well prepared heading into the meetings.

While the framework is presented, it should be noted that the effective planning and execution of such instructor/student interactions is not trivial. As an instructor, the art of performing as both instructor and mock "project supervisor" benefits from both preparation as well as experience. In these areas, our model can only assist with the former.

Conclusions & Future Work

This paper has described the VCVD project and the coaching sessions contained therein. Student perceptions support the situated intent of the VCVD laboratory project as well as the perceived effectiveness of the coaching sessions. In these coaching sessions, a structure of episodes was found which is topic centered and consists of four stages: surveying, probing, guiding and confirmation. Feedback is crucial to student success. Preliminary examination of coaching sessions with the episodes framework supports both effectiveness of the coaching sessions as well as demonstrates the episodes framework as a potentially powerful tool in discourse analysis, especially for feedback. In addition, the topic flows and component structure lend themselves as a tool for scaffolding instructor development. However, further research is necessary to validate these preliminary findings. In addition, other potential research questions which may be explored by coaching session analysis by the episodes framework are given below:

- Which episodes topics are common to all coaching sessions and which are brought up on a team by team basis?
- What is the duration of each of the common episode topics in each team's coaching session?
- How do individual episode components vary between teams? Is there a common length to each component?
- Are there episode topics that typically accompany each other?
- Are episode topics aligned to instructional goals for a given coach?
- Are episode topics aligned to deliverables for the students?
- How does a coach change with time? Do common topics change? Does the composition of episodes change?
- Are particular episode compositions, orders, or qualities more effective than others?
- What degree does the episodes framework transfer to different coaches interacting in different contexts?

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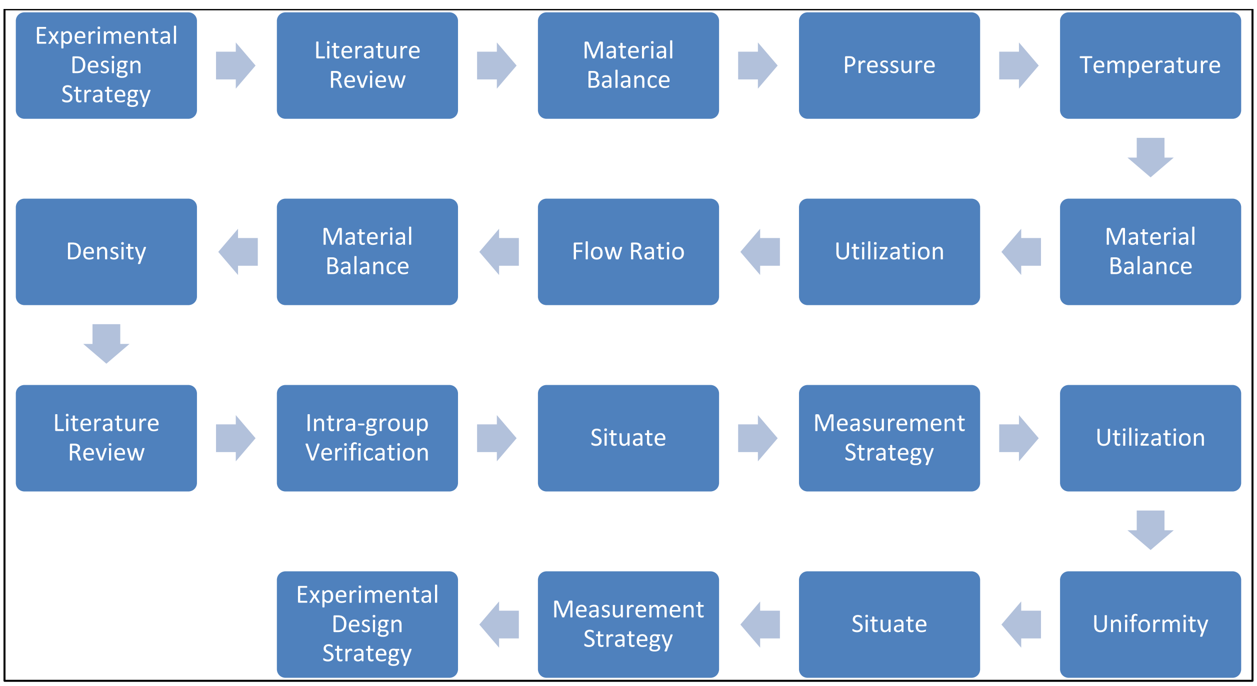
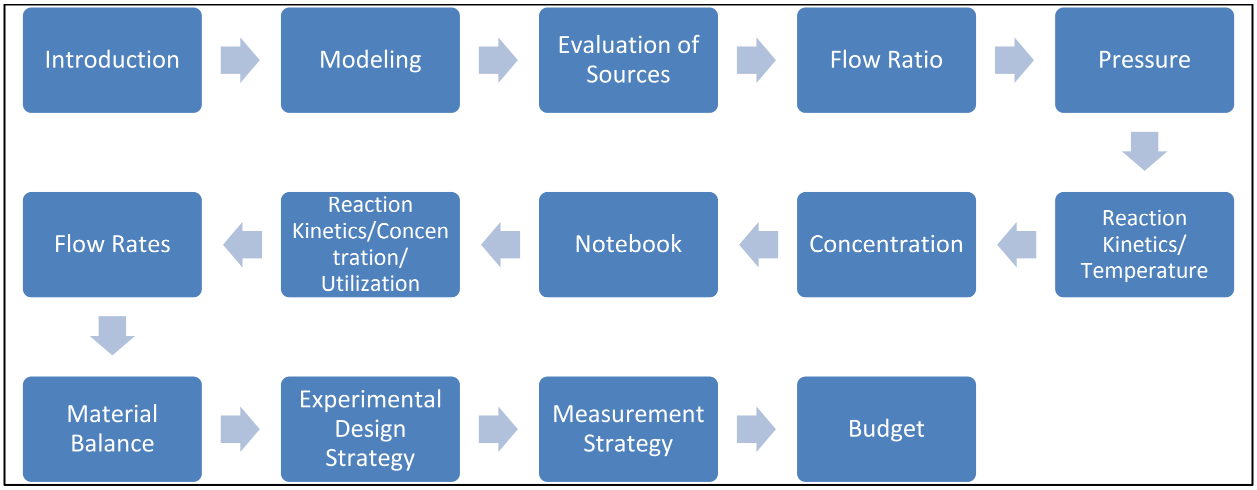
Appendix 1: Team B, C & D Topic Flows

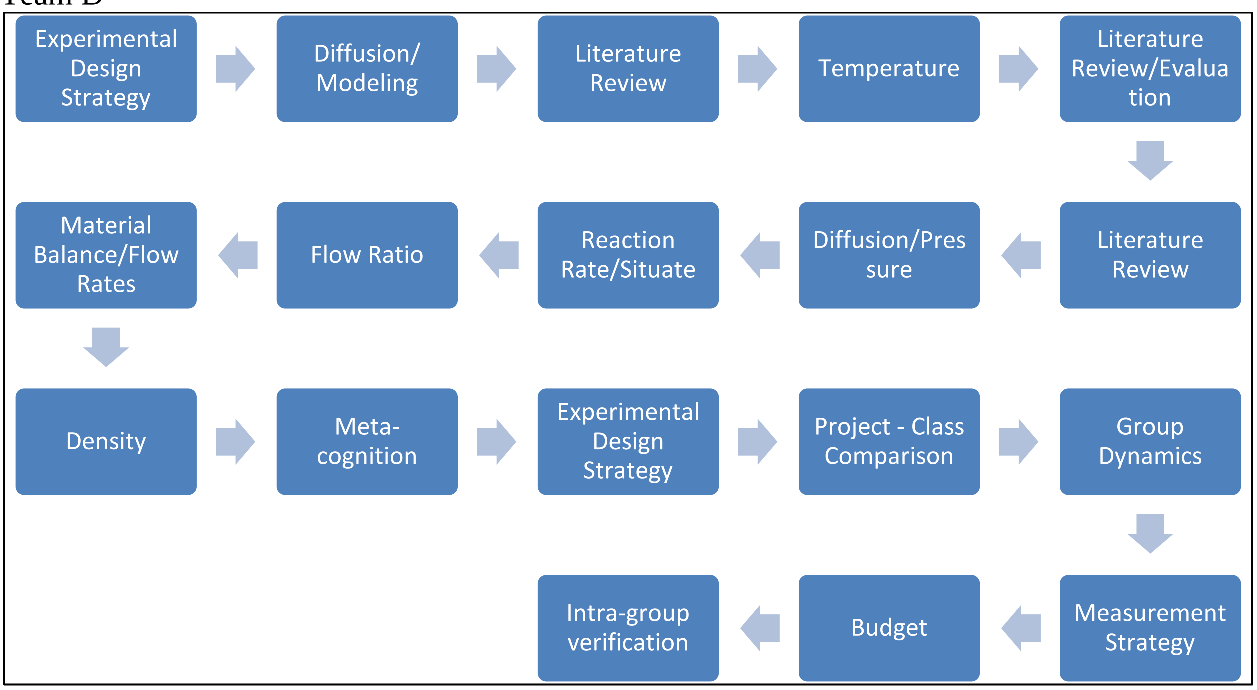
Team B



Team C


Introduction
Modeling
Evaluation of Sources
Flow Ratio
Pressure
Reaction Kinetics/ Temperature
Concentration
Notebook
Reaction Kinetics/Concentration/ Utilization
Flow Rates
Material Balance
Experimental Design Strategy
Measurement Strategy
Budget

Team D


Experimental Design Strategy
Diffusion/ Modeling
Literature Review
Temperature
Literature Review/Evaluation
Literature Review
Diffusion/Pressure
Reaction Rate/Situate
Flow Ratio
Material Balance/Flow Rates
Density
Meta-cognition
Experimental Design Strategy
Project - Class Comparison
Group Dynamics
Measurement Strategy
Budget
Intra-group verification