Toward Integrating Reeves' Autonomy Supportive Teaching Scale to Support Facilitator-Student Observation in a Problem Based Learning Environment

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***Abstract*—This research paper considers the integration of Reeves' autonomy supportive teaching scale (ASTS) as an observation tool for problem based learning (PBL). The work is motivated by our interest in understanding the nature of effective facilitation in PBL settings, a recognized challenge of PBL implementation. We report on our efforts to use ASTS to characterize instructor-student interaction that balances the need for student autonomy inherent to PBL with the learning outcomes that an instructor seeks. Four members of a research used a modified version of the ASTS to analyze classroom recordings from an introductory aerospace engineering course. We considered interactions between the facilitator and students that occurred at the level of whole-class and individual group. We report on three representative cases that highlight challenges in the use of ASTS in practice. We found that using the ASTS to evaluate autonomy in the PBL classroom supports productive conversations within the research team that allowed for deliberation on several topics relevant to PBL in undergraduate engineering. This work has implications for understanding the role of discourse in supporting student autonomy within PBL classrooms. Specifically, the method and tool for assessing PBL facilitation might be adopted by educators to guide and help instructors understand how to effectively facilitate PBL problems in the classroom and find balance between student autonomy and instructor directed action.**

***Keywords*—PBL, facilitation, student autonomy, autonomy supportive teaching**

I. Introduction

This research paper considers automony-supportive facilitation in Problem-based learning (PBL) environments. PBL hold promise in engaging students in authentic practices which closely resemble those in professional contexts [1]. In undergraduate engineering specifically, the practices in which students engage in these environments sharply contrast with those in more traditional, didactically-oriented engineering classrooms, moving from closed-ended, well-structured problems to more open-ended, ill-structured ones [2]. Engaging students in PBL presents an opportunity to respond to a variety of issues in contemporary education, but designing and implementing PBL is difficult and we currently lack understanding of how faculty might facilitate an effective PBL experience for students [3], [4], [5].

An important feature of PBL is the student-centered nature of the learning experiences and environments [6], [7]. Students are expected to drive the problem engagement while faculty take the role of facilitator. In this way, one dimension of PBL explored here involves the extent to which student *autonomy* is supported to enable their growth as learners who actively construct knowledge. This study considers the integration of Reeve's Autonomy Supportive Teaching Scale (ASTS) as an observation tool for PBL [8]. This integration is toward understanding the student-faculty dynamic in PBL (and other active learning environments), which is important to informing both faculty training and best practices for maximizing student learning.

ASTS is an observation framework with the potential to support this research agenda. However, implementation is not straightforward in practice. We describe our efforts to use ASTS to characterize instructor-student interaction that balances the need for student autonomy inherent to PBL with the learning outcomes that an instructor seeks. Our objective is to share our experience to foster a community discussion that can inform further adaptation and integration. This work is framed by three broad questions: *What works in integrating ASTS as a PBL observation tool? What challenges are there in integrating ASTS as a PBL observation tool? What relevant issues does this integration foreground?*

We consider specific cases of student-faculty interaction at units of analysis that consider whole class interaction, as well as interaction with individual student groups. Before reviewing our methods and reporting on specific cases in the Preliminary Results section, we consider important background literature related to pedagogical structure and learner autonomy, classroom observation, and details of Reeves' autonomy supportive teaching framework.

II. BACKGROUND

A. Student-centered pedagogy and learner autonomy

Student- (or learner-) centered pedagogy is rooted in constructivism and is typically associated with active learning frameworks in which students are increasingly responsible for their learning [9]. For some time, there has been pressure within engineering to reform educational practices to better prepare engineers for practice [10]; moving from teacher- to learner-centered pedagogy is among those reforms [11], [5]. This shift necessarily places instructors in a facilitator role, which is fundamentally different from the lecture-style classrooms to which they may be accustomed [5]. In student-centered spaces, facilitators must find ways to motivate students to direct their own learning; something students themselves are not accustomed to and may struggle to adapt to [12], [13].

This work is motivated by our interest in understanding the character of effective facilitation in PBL settings, a recognized challenge of PBL implementation [3], [4], [5]. We specifically sought to analyze interactions between students and the instructor in a PBL setting using an established classroom observation protocol that aligned with values espoused in PBL, namely, student autonomy. Further, we are interested in observing this interaction at a granular level that might support understanding of specific issues, tied to learner autonomy, that positively or negatively impact learning outcomes. In this way, work by Reeve (2016) provides guidance and a classroom observation rating tool to assess autonomy-supportive teaching.

Analyzing teaching behaviors using observational protocols is ubiquitous in K-12 teaching, and a few similar tools have been developed for conducting college-level classroom observations as well. Popular instruments include the Teaching Dimensions Observation Protocol (TDOP) [14], the Reformed Teaching Observation Protocol (RTOP) [15], and specifically in STEM contexts, the Classroom Observation Protocol for Undergraduate STEM (COPUS) [16]. While designing the present study, our research team set out to find an observational tool that was designed for evaluating teaching PBL in college-level settings, and specifically evaluating dimensions of PBL our team is interested in understanding. Through a review of various observational tools, we judged the ASTS to be suitable for our needs for two reasons. First, no other observation tools that we encountered had a level of granularity supported by ASTS. Second, due to its focus on autonomy, our research team concluded that ASTS is well-aligned with the student-driven nature of PBL.

B. Reeves' Autonomy-Supportive Teaching

Drawing on work by [17], Reeve argues that instructors adopt a *motivating style* which can be considered oriented toward control or autonomy. Broadly, autonomy support is the "interpersonal sentiment and behavior the teacher provides during instruction to identify, then to vitalize and nurture, and eventually to develop, strengthen, and grow students' inner motivational resources" while teacher control, on the other hand, is the "interpersonal sentiment and behavior the teacher provides during instruction to pressure students to think, feel, or behave in a teacher-prescribed way" [8].

Reeve (2016) conceptualizes teaching motivational styles along a bi-polar spectrum with poles of autonomy supportive and controlling. A given instructional behavior in this way can be considered to be varying levels of either autonomy-supportive or controlling. Reeve offers a bipolar continuum observational tool that reflects this conceptualization, comprising six empirically validated instructional behaviors that observers can use to assess an instructor's motivating style. This observation tool is presented as a Likert-scale assessment ranging from 1 (Never) to 7 (Always) for each pole. The behaviors, listed as Controlling/Autonomy-Supportive, include:

- Takes only the teacher's perspective / Takes the students' perspective
- Introduces extrinsic motivators / Vitalizes inner motivation resources
- Neglects to provide explanatory rationales / Provides explanatory rationales
- Uses controlling, pressuring language / Uses non-pressuring, informational language
- Counters and tries to change negative affect / Acknowledges and accepts negative affect
- Displays impatience / Displays patience

Reeve describes the use of ASTS in terms of "three critical motivational moments" (Reeve, 2016): 1) pre-lesson reflection (planning and preparing), 2) lesson begins (inviting students to engage in the learning activity), and 3) in-lesson (addressing and solving problems that arise). Further, he suggests that the certain behaviors should be "observed" in particular motivation moments, but not others. For example, Reeve suggests that the extent to which the instructor takes the teacher's (or student's) perspective occurs during pre-lesson reflection. In conducting observations, the idea is to evaluate the extent to which the instructor is engaging the autonomy supportive (or controlling) behavior through operational characteristics. The operational characteristics associated with autonomy-supportive behaviors as we understood them from reviewing [8] are shown in Table 1. In practice, we found it challenging (perhaps, limiting) to constrain observation of some behaviors to only particular motivational moments. Similarly, whether or not an operational characteristic could be observed and/or verified proved difficult at times, as will be discussed in the results and discussion sections. In the next section, an overview of the PBL environment, as well as adaptation of ASTS and its application in the PBL setting are described.

III. METHODS

In this section, the instructional context in which observational data was collected is described. This is followed by a brief description of adaptation of the ASTS and application by the research team.

TABLE I
OPERATIONAL CHARACTERISTICS OF AUTONOMY-SUPPORTIVE TEACHING

Autonomy supportive behavior	Operational characteristic
	”In synch” w/ students
Takes students’ perspective	Aware of students’ needs, wants, goals, priorities, preferences, emotions
	Invites, asks for, welcomes, and incorporates students’ input
	Autonomy (ask students what the want to do an allow them to do it)
	Competence (offers an optimal challenge in a failure-tolerant environment)
Vitalizes inner motivational resources	Relatedness (provides opportunity to interact w/ classmates)
	Curiosity (asks questions, allows use of exploratory behavior to fill knowledge gaps)
	Interest (provides opportunity to learn something new and improve understanding)
	Intrinsic goals (frames learning activity as opportunity for personal growth, skill development)
Provides explanatory rationales	Explains why
	Identifies value, benefit, utility
Acknowledges and accepts negative affect	Recognizes and validates negative affect
	Allows students to provide suggestions
	Asks questions to acquire information as to why students are struggling or unsure or approaching things in a particular way
Uses informational, non-pressuring language	Uses language that is not overtly prescriptive
	Observes and listens to students; avoids urgent language

A. PBL Context and Observational Data Collection

The observational data used in this study was collected from an introductory aerospace engineering classroom from a large public institution in the southeastern United States. The course was designed such that over the course of the semester, students engaged three different open and ill-structured problems, each carried out over 3-4 weeks. Class met once per week for 75 minutes, and a typical class meeting comprised three phases: faculty facilitated ramp-up/planning discussion with the class (15-20 minutes), students working in groups of three with the faculty member circulating among groups (45-55 minutes), and a debrief discussion where cross-group issues were discussed (10 minutes). As this is part of a larger study, we know that face-to-face group work was largely constrained to the class, with students working asynchronously outside of class to advance and document their problem solutions.

The instructor has been teaching for 10+ years using both didactic and active pedagogies. PBL was not a new idea but implementation for this course was more intentional than in the past. The most striking change for the faculty was a commitment to not lecture on specific topics prior to engaging students in the problems. Instead, the problems themselves were the vehicle for students’ acquisition of relevant knowledge, with the faculty curating relevant knowledge resources for students to consult. The class comprised (mostly) second-year students and for the vast majority, this was their first PBL experience.

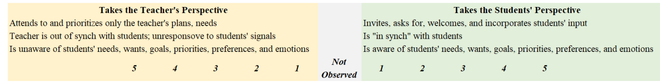


Fig. 1. ASTS scale example for Perspective behavior taken from [8]

As is policy at the institution post-COVID, all class meetings were recorded so that they could be made available to students. These class recordings supported classroom observation as part of an IRB approved study (redacted). The faculty member is recorded at all times through wireless microphone, while recordings of students are only captured when the faculty member is talking to a specific student group. This arrangement supported observation of whole-class interactions as well as some faculty-small student group interactions. We considered recordings associated with one problem from two different sections of the course. Students worked on the problem over a three week period in the fall of 2022, thus we had a total of six recordings to consider. ASTS was applied to representative examples of the ramp-up and debrief discussions, as they largely followed the same general pattern. Sampling of student-small group interactions was random, but is also limited by the quality of data collection (i.e., not all small group interactions are discernible due to background noise).

B. Adapting Reeve’s Autonomy-Supportive Teaching Scale

ASTS as described in [8] was modified in three ways for use in our research. First, we (re-)combined the individual unipolar scales for each of the six behaviors into bipolar scales (see Figure 1 for an example). As Reeve describes, his original (and even current personal) conceptualization of ASTS considers a single, bi-polar rating tool. However, with reference to findings from other researchers he concedes that confounding factors related to issues like who is being rated and the duration of the rating time may justify consideration of individual rating forms. As our application considered the same faculty across multiple instances of whole-class and small-group interactions, a combined scale that allowed us to contend with instances of both autonomy-supportive and controlling facilitation style, by the same faculty, within the same pedagogical approach, was vital. Second, we added a ”not observed” option in order to accommodate cases where a particular behavior could not be readily observed. In application, we found that it was not possible to observe instructor behavior related to students’ negative affect, if it was even present (more on this later).

Finally, we used a five-point, rather than a seven-point scale for evaluation. This decision was made because as a research team, discerning observations at a seven-point resolution did not seem feasible (i.e., we were not sure how to distinguish difference along the scale). In application, even judging along a five-point scale proved challenging, as is discussed later.

C. Applying the Adapted Scale

Four members of our research team used the modified version of the ASTS to analyze classroom recordings from the introductory aerospace engineering course. We considered interactions between the instructor and students that occurred at the level of whole-class and individual small-group. Following Reeves' consideration of "motivational moments" during which autonomy-supportive behavior can occur, one member of the research team identified a set of recorded instances (noting the period of time to be watched) from across the six class recordings (three for class section A and three for section B). This included consideration of the ramp-up and debrief phases of each class, when the discussion, and therefore unit of analysis, was whole-class level. These phases were also more didactic in nature, with the faculty talking for extended period of time, while also inviting student input. Recordings that we considered also included multiple instances of faculty-student group interaction, representing periods of time when students were working with their small groups and the faculty was circulating to check-in on student progress. These interactions typically lasted for 2-3 minutes. These small group interactions are important because they provide opportunities to consider the variation in autonomy-supportive vs. controlling modes of facilitation that might be attributed to differences in student prior knowledge, intended learning outcomes, and the state of student progress relative to the final submission deadline.

Each member of the team applied the adapted scale individually to previously identified observation instances. Individual scoring and the interactions under consideration were discussed in subsequent research team meetings, during which our team collaboratively worked to find consensus for each item in the ASTS. This process was applied to one problem that students worked on over a three week period. Though we do not believe knowledge of the problem is important to understanding the results and discussion, the problem statement is shown in Appendix B.

In the next section, we consider preliminary findings derived from application of ASTS.

IV. Preliminary Findings

In presenting preliminary findings, we are interested in demonstrating the value and challenges of implementing an observation tool like ASTS in a PBL environment. The course instructor supported students' autonomy at varying times during a single lesson and more broadly over the multi-week duration of their problem engagement. This section outlines specific examples of autonomy-supportive behaviors that occurred at key points in the instructional unit. Each example represents a specific case of interaction captured in video data and includes the ASTS as applied by the four member research team. A more detailed discussion of the most relevant or standout behavioral dimensions of the ASTS are provided for each case.

We consider three cases. The first two cases allow us to describe challenges of implementation of ASTS that resulted in convergence among the researchers, as well as a divergent case. The third case presents an instance where a controlling approach to teaching maybe warranted, even where student autonomy is generally important to the pedagogical strategy of PBL.

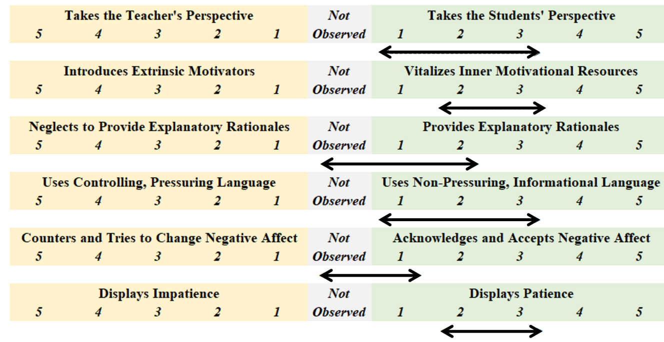


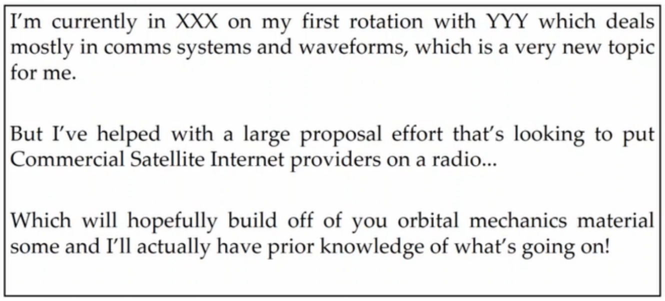
Fig. 2. ASTS scoring from research team for Case 1 observation

A. Case 1: Ramp-Up: Former Student Anecdote

This first case occurred during the ramp up phase on the first day of students' in-class engagement with the problem. At this point, students were expected to have reviewed the problem statement and responded to a pre-problem engagement reflection activity. As mentioned previously, for the majority of students, this is their first time engaging with a problem of this nature (open-ended and ill-structured) in a classroom setting. Their level of confidence was relatively low, based on a reflection question that asked students *How confident are you that you can solve this problem?* This question was asked of students throughout the semester starting with the first day of class, before they had seen any of the problem statements, and then before and after each problem they engaged. Upon reviewing the problem statement for the first time, overall confidence of the class decreased from their initial (first-day of class) confidence about being able to solve open, ill-structured problems on the first day of class.

The ramp up phase lasted for approximately 15 minutes. The instructor introduced the problem for approximately seven minutes. He then spent about two minutes talking through his mental model of the appropriate high-level process for solving this type of problem (an analysis problem). At that point, he shifted to acknowledge/foreground that the students are being challenged and that he expects they will be uncomfortable and uncertain as they engage the problem. In anticipation of this, the instructor employed classroom materials – a presentation slide as well as an anecdote – to prepare students for what could be considered the complex character of PBL problems and a sense of ambiguity while engaging in PBL work. The range of ASTS scores resulting from the four researchers for this ramp up case is shown in Fig. 2.

From the ASTS scoring of Fig. 2 it is evident that the research team agreed that, in general, the instructor was autonomy supportive, though there is variability in the level of that support across the six behaviors. The greatest variability (i.e., researcher disagreement) was associated with *Takes the*


I'm currently in XXX on my first rotation with YYY which deals mostly in comms systems and waveforms, which is a very new topic for me.

But I've helped with a large proposal effort that's looking to put Commercial Satellite Internet providers on a radio...

Which will hopefully build off of you orbital mechanics material some and I'll actually have prior knowledge of what's going on!

Fig. 3. Former student email

Students' Perspective, *Provides Explanatory Rationales*, and *Acknowledges and Accepts Negative Affect* behaviors. For two behaviors, there was at least one researcher who scored "not observed." For the remainder of this case, we return to the aforementioned presentation slide anecdote, to unpack some of this variability based on a particular aspect of the ramp-up that stood out.

The presentation slide which provided evidence of the instructor taking the students' perspective read: *"You may now be thinking... I don't know anything about aircraft design! That is ok."* Below that, the text from the former student's email was quoted, as shown in Fig. 3. While the instructor shared this slide, he declared, "*...you may say, but I don't know anything about aircraft design. How are you throwing me into this? Also, I might not necessarily care about aircraft. This isn't fun, why do I want to do this? This is an email that I received last week from one of my former grad students. This student is currently working... with a major aerospace company in comm [sic] systems and wave forms. It was not the focus of anything that they did in [school], but... they were able still to find a way to learn about it, get engaged... they're trying to take some of their existing knowledge and port it over to this new problem, one of which they don't have very much experience with.*"

This anecdote shows evidence of planning PBL curriculum that fosters autonomy on the *Takes the Students' Perspective* dimension. In this case, the instructor planned a slide where he prepared students for facing problem content to which they hadn't yet been introduced, suggesting that he is "in synch" with students and aware of their *emotions, needs, and preferences*, an operational characteristic of this ASTS dimension. However, it was difficult to agree upon the level of this behavior overall within the 15 minute ramp-up phase (i.e., exactly how much weight that this particular anecdote has within the ramp-up varied by researcher).

This case also seemed to demonstrate that the instructor *Provides Explanatory Rationales* at a high-level of activity; the instructor is aware that participating in PBL classroom activities, marked by ambiguity in problems and a departure from traditional didactic instruction, is most likely a novel experience for engineering students. However, it is one that mirrors realities of professional practice and in this way, *identifying the value and utility* of engaging in this type of work, in that it closely resembles that of professional engineering, is instrumental in supporting autonomy. While this explanatory rationale portends a long-term value, that value may not connect with the immediate problem context, which led to one researcher scoring this behavior as "not observed" at any point in the ramp-up.

Finally, there is the potential that sharing this anecdote evidences that the instructor *Acknowledges and Accepts Negative Affect*. While three researchers indicated that this behavior was "not observed" during the ramp-up phase, this was the interpretation of one researcher. The consideration here is that the instructor predicted negative affect and validated that sentiment as "okay." What is in question here is whether or not such preemptive recognition is valid within ASTS, or if it is only appropriate to observe this behavior when it is actually on display by students.

Of interest in this case is the novel character of curriculum materials when examined through the ASTS: whereas traditional engineering curriculum materials such as slideshows often serve a single purpose of transmitting content, PBL materials such as those in the present case can serve a qualitatively different function–they work in acknowledging and attending to the socioemotional needs of students when they are faced unfamiliar engineering activities, i.e., less-structured PBL problems. Because PBL problems often pose ambiguity for students as they encounter previously uncovered content in a problem, taking measures to acknowledge this is crucial for fostering autonomy in the classroom. This issue becomes even more salient when considering how PBL activities might contrast with those in other engineering courses, which are often characterized by didactic models in which students receive explicit instruction and are tasked with internalizing that knowledge in order to reproduce it in the context of well-structured problems. During a follow up interview, the instructor expressed that this anecdote and slide was prepared as a preemptive measure to prepare students for uncertainty precisely because, when considering the entire undergraduate program in which this course was a part, students are predominantly responsible for course content explicity covered in class and little else.

B. Case 2: Students-at-Work: "If I was Your Boss..."

The second case occurred during the third and final in-class work session before students would submit their final problem solution artifact. Here we consider an interaction between the instructor and a student group, which occurred as the instructor was circulating the classroom as students engaged the problem with their 3-person team. Generally, these *students-at-work* periods were characterized by an autonomy-supportive instructor circulating the classroom, using inquiry to gauge student groups' progress and providing feedback based on their current progress through the problem. This case provides an uncharacteristic instance, compared with all other observations we conducted, in which the instructor engaged in controlling behavior. The ASTS scoring results from the research team are shown in Fig. 4, again reflecting variability

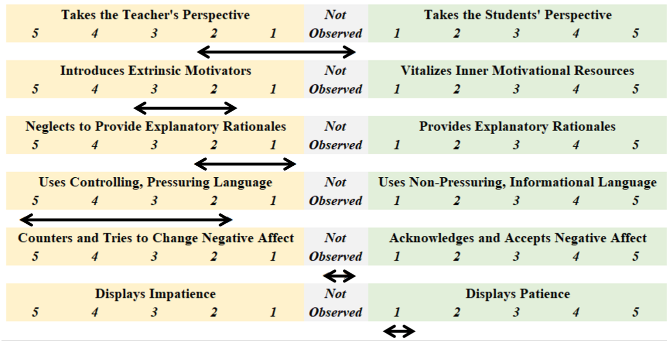


Fig. 4. ASTS scoring from research team for Case 2

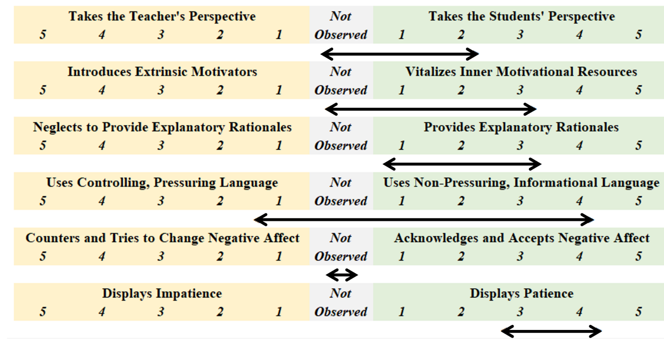


Fig. 5. ASTS scoring from research team for Case 3

in scoring of behaviors but a general agreement as to which side of the scale the instructor behaved. In this case, the interaction lasted for approximately three minutes, and the instructor initiated conversation by asking the students how they planned to communicate the results of their analytical modeling. He asked a number of questions toward getting the students to narrow in on what information would make sense to present and how to present that information. A student from the group presented the instructor with the contents of a file that consisted of raw data which the group had created using spreadsheet software and calculations from their model development. Upon looking at this spreadsheet displayed on a student's computer screen, clearly frustrated, the instructor remarked, *"No. You would never give an Excel spreadsheet to your boss and say, 'here's a bunch of data.' No."*

We determined that this interaction between the instructor and the student group reflects the *Introduces Extrinsic Motivators* dimension, a controlling behavior. While at other points in the semester, the instructor leveraged the idea of interacting with a technical manager to effective ends, this interaction specifically demonstrates the instructor *giving consequences for undesired behaviors*, an operational characteristic of this behavioral dimension. This interaction positioned the instructor and students in a controlling power position, akin to a workplace supervisor with the power to fire employees for poor performance. This interaction communicated to students that negative consequences would result from sharing work that lacked in effort or a firm direction. When compared to the autonomy-supportive pole of this continuum, in which the instructor exhibits behaviors that serve, for example, in *piquing students' curiosity*, giving consequences for undesired behaviors – even when these consequences are posed as potentially occurring in a future engineering work context –makes it apparent that the instructor is imposing extrinsic motivating forces rather than engaging students' intrinsic motivations.

The research team agreed that the instructor still appeared to *Display Patience* overall. However, this autonomy-supportive behavior appeared to be overshadowed by the controlling behaviors, not only in total number, but also in the strength of those behaviors. The combination of behaviors seemed to invoke a particular controlling tone. Here, the overall (though highly variable) researcher sentiment was that the instructor *Used Controlling, Pressuring Language*, because he specifically *prescribed* plotting data to the students.

In combination with the extrinsic motivator behavior, this worked to influence students' actions by specifying the conditions for their acceptable participation. Generally, some amount of controlling language may be warranted. Indeed, in this case, suggesting to the students that they might plot the data in their spreadsheet is arguably a valid prescription that we might expect from a course instructor, especially as the submission deadline was nearing. However, in this case, what may be a normally acceptable prescription seems to be undermined by the "if I was your boss" extrinsic motivator.

C. Case 3: Shifting Students' Focus from Component Selection to System Analysis

The third case occurred on the first day of working on the problem during a *students-at-work* phase. The instructor circulated the classroom and conducted feedback sessions with student groups. In one such case, he initiated conversation with a group by asking them about their general plan of action. The students talked about components – batteries and motors – picking up on a part of the problem statement that seemed to be taking them in a direction of treating the problem as a component selection problem, rather than the intended trade-space analysis that would inform component selection by a different part of the hypothetical AIAA competition team that they are part of. The research team's ASTS scoring for this case is shown in Fig. 4. Generally, the researcher team scored this interaction as autonomy-supportive, though variability in that scoring is apparent. When the students responded by discussing potential options for batteries and motors suitable for the AIAA challenge, the instructor used inquiry to steer the discussion in a different direction. In this way the instructor did not dictate what the students should do next; instead, he employed a series of probing questions to encourage deeper thinking and lead students in the "right" (i.e., intended) direction for engaging the problem. As the students shared their progress, the instructor expressed a concern, saying:

"My one concern with that [approach] would be that if we're trying to figure out power, what is that power that we're looking for? If we're defining combinations of power to weight,

and it's a ratio, what are we trying to determine? Let's say it's even thrust; is it a desired or is it the actual? So is it the target I want to hit or is it what I can actually do? That determines if I know all my components, right? But in this case, where we're not specing [sic] *things out. We're just trying to get a feeling for how big it should be. We're really talking about a target. So it's how much power is required in order to carry out what I need to do, given some kind of weight, right? So is that power greater than one? Is it less than one compared to my weight? Because it's a ratio. So do I need to generate more power at a 1:1 ratio to my weight? Is it a 2:1 ratio? Is it a 30:1 ratio? And then, weight over wing area, if wing area becomes a surrogate for lift, how big does my wing need to be compared to my weight? How do those things relate to each other? So I would stay at a high level and think about the analysis elements, right? To me, choosing motors and components is a different type of problem. That's a selection problem. I'm trying to think of, how can I model the system? What can I do with it there? So some food for thought."*

By posing these questions, the instructor was encouraging students to think about the problem at a higher level, one that would hopefully steer them away from choosing motors and components (a guess-and-check strategy) toward an analysis based approach instead. A follow-up interview with the instructor revealed that many student groups were prone to choosing components, and a struggle he experienced with this particular problem involved redirecting students to focus on developing a trade-space model instead.

This interaction illustrates a representative case of the instructor's engagement in the autonomy-supportive behavior *Uses Non-Pressuring, Informational Language* during facilitation. Specifically, the use of inquiry as a means to avoid using prescriptive language as it is exemplified in the ASTS, e.g., *"you should"* or *"you have to"* in directing students' activities in the classroom is a useful example of fostering autonomy in learners. It demonstrates how the instructor possessed a commanding knowledge of the problem but refrained from explicitly instructing students on the steps required to solve it; rather, his sequence of inquiries provide evidence of attempting to support autonomy through intentional use of language in this inquiry-based form.

This interaction also illustrates the instructor *Providing Explanatory Rationales* by articulating the reasoning behind analyzing the power-to-weight ratio as well as working towards generating a model in lieu of selecting aircraft components. By asking questions involving parameters of the plane, the instructor helped students see that understanding these fundamental relationships is crucial for making informed decisions about their design (i.e., the components to be selected eventually). Next, the instructor clarified that choosing components as a course of action intended to solve the problem is representative of a selection problem rather than a trade-space analysis. Although this student group had originally sought to find components suitable for the AIAA challenge, the instructor redirected students' actions in solving the problem by rationalizing attending to analysis elements and modeling the system. His guidance provided the necessary context for why simply choosing components without understanding the goals of the problem might not lead to successful problem engagement.

This approach showcases the instructor's strategy of fostering autonomy by reframing the problem, providing clear rationales, and speaking in a non-pressuring manner intended to contribute to an autonomy-centered learning environment. While the intended effect is to steer students to engage the problem in ways that meet the particular learning aims of the designed problem, contrary to Case 2, the nature of discourse appears less controlling.

V. Discussion

This work is focused on understanding the nature of effective facilitation in PBL environments, recognizing that student-autonomy within the learning environment is important to that pedagogical approach. This is motivated by recognition that facilitation remains an important hurdle to PBL adoption [3] [4] [5], for which more granular investigation of classroom practices is warranted [4]. With that motivation in mind, this paper shares our exploratory work to integrate Reeves' autonomy-supportive teaching scale to understand student-facilitator interactions at a granular level. Here, we discuss what we consider preliminary findings by revisiting our three research questions: *What works in integrating ASTS as a PBL observation tool? What challenges are there in integrating ASTS as a PBL observation tool? What relevant issues does this integration foreground?*

A. What works? What is challenging?

We start with consideration of what works and what proved challenging. At a high-level, applying ASTS did not prove overly difficult. That is, in considering the six behaviors together, we generally ended up on the same side of the ledger, and felt comfortable distinguishing autonomy-supportive from controlling facilitation. However, as evidenced in Figs. 2, 4, and 5, there was often high variability in scoring individual behaviors for a given observation.

One reason for such variability may owe to our re-purposing of the tool. Where Reeve [8] may have intended the scale to be used during the observation of a full lesson (e.g., as in the professional training of a K-12 teacher) our application considered specific moments within a full lesson. Toward overcoming this particular challenge, it may be enough to simply determine if a particular behavior is autonomy-supportive, controlling, or not observed, eliminating the need for the Likert-scale.

Another challenge is related to the operational characteristics associated with the six behaviors (see Table I). The specific meaning of these characteristics is not always clear and therefore, recognizing whether or not those characteristics are present is also, at times, not clear. For example, "competence" is defined as offering an optimal challenge in a failure-tolerant environment. What constitutes an "optimal challenge?" Does optimal refer to the whole problem that students have been asked to engage, or should focus be on whether sub-tasks/problems that are scaffolded through facilitation are optimal challenges? Similarly, what constitutes a failure-tolerant environment and how does that relate to feedback and assessment mechanisms? Leveraging these operational characteristics requires a deep understanding of the context and philosophies of the learning environment that can be messy and nonlinear, which is especially true of PBL.

A final challenge relates to the nature of the interaction in the PBL environment. The facilitator-student interaction will often occur in small groups; a conversation between the instructor and a few students while other students continue to work nearby. There is a need for good data – data that allows for intimate interaction to be fully captured and observed – which can be challenging in engineering classrooms, which often have a large student to instructor ratio. This is vital to capturing and analyzing the facilitator-student interaction, especially as it might relate to negative affect, a limitation in this work that resulted in that behavior typically being ”not observed.”

B. Foregrounding of relevant issues

Despite the challenges, further research to integrate ASTS as a tool that enables more granular units of analysis is worthwhile. We hold this belief because of the number of valuable discussions use of ASTS led to within our research team and how it has factored into our thinking about PBL. One important issue foregrounded in this exploratory study, encapsulated in Cases 2 and 3, relates to the issue of balancing autonomy-support and controlling facilitation. A central intention of the PBL model is to provide authentic activities that resemble those of professional engineering practice, but oftentimes learners require direction when dealing with complex and ill-structured problems. In this way, the instructor-as-facilitator might aim to strike a balance between adopting a mixture of autonomy-supportive and controlling behaviors at certain times and for certain reasons during facilitation.

Ideally during the planning of a PBL problem, an instructor will possess the knowledge required to successfully solve the problem. When students struggle with certain portions of the problem during facilitation, the instructor might determine that ”prescribing” a course of action is warranted, and this course of action is informed by the instructor’s experience with the problem and/or the broad learning objectives. Although Reeve’s ASTS is toward fostering autonomy in a classroom, PBL instructors may need to adopt more controlling behaviors for some situations, and we can imagine several such scenarios.

First, if the difficulty of a problem poses a threat to students’ chances of successful engagement, a more controlling approach may be warranted in order to avoid student frustration. Such frustration can be counter to the intrinsic motivation instructors seek to leverage in autonomy-supportive learning environments. A second scenario, related to the first, are instances when time is running out (i.e., the deadline for problem engagement is approaching) and the instructor wants students who appear ”stuck” to keep moving forward. Again, providing more prescriptive actions may be warranted to keep students’ intrinsic motivation intact. A third scenario is when the instructor seeks to broker student acquisition and use of specific domain knowledge, but in a way that goes beyond simple transmission of knowledge via didactic pedagogy. Similarly, moving students away from forms of engagement that are not aligned with overarching objectives of the problem under consideration may require more controlling forms of facilitation.

Such scenarios present a dilemma for instructors who seek to support autonomy in the classroom while at the same time ensuring that students successfully engage with a problem. On one hand, an instructor might find value in allowing students to make mistakes while working in a PBL environment. Students should be given the agency to attend to a problem in a way they see fit regardless of the appropriateness of their problem solving strategy; learning from these mistakes is an integral part of the overall learning process. At the same time, however, formal education poses constraints including limited time allotted per problem as well as a potentially wide range of individual groups’ progress in solving the problem. The instructor, therefore, is tasked with balancing these issues typical of classroom teaching–attempting to ensure the success of every student and covering course materials in a timely manner–with fostering autonomy.

With these challenges in mind, the instructor might deem it necessary to intervene with more controlling behaviors. Our data provides concrete examples of that behavior to reveal the delicate nature of facilitating PBL and convey the struggles faced by instructors in striking a balance between autonomy-supportive and controlling facilitation.

VI. Conclusion

In implementing PBL into undergraduate engineering coursework, we envision a shift from dominant lecture-based engineering teaching approaches to more autonomy-supportive environments. We believe the PBL environment can occasion this shift, but we also carefully note that the behavior of an instructor is instrumental in fostering autonomy in students, rendering them active agents responsible for their learning. Our use of the ASTS in this study has helped reveal some of the tensions in running a PBL classroom. Based on this work we view additional research rooted in classroom observation at a granular level as a necessary step to provide feedback and inform faculty development in ways that allow them to feel more comfortable implementing PBL. ASTS provides a good starting point but requires refinement to support more rigorous PBL research.

VII. Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. 2117224. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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