[WIP] A Case Study of One Team's Emergent but Unorthodox Collaboration Practices to Negotiate Ambiguity, Uncertainty, and Confusion in an Undergraduate Introductory Computing Course

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I. Introduction and Background

In this empirical, work-in-progress study, we observe a pair of students working together, seeking to understand how different collaborative practices can support productive engagement with moments of *ambiguity*, *uncertainty*, and *confusion (AU&C)*. Successful engineering practice depends on working through AU&C, and professional engineers often rely on collaboration as a tool for doing so. Incorporating problems that elicit AU&C in the engineering classroom shifts the focus from simply completing the assignment to preparing students to "develop ways of sense-making and habits of mind that align with the higher-level capabilities needed in practice" [1, p. 1-2]. While there are ample studies on the role of AU&C and effective teamwork on learning, there is a gap in the literature on what successful teamwork entails when addressing AU&C. Most instruction on best teaming practices offers guidance about how an individual student should act to be a good teammate within collaborative environments [2], [3]. This paper reports a case where a pair of students appear to collaborate productively but not in the canonical ways that educators suggest a good teammate should act. We seek to characterize this pair's interactions to introduce alternative conceptions of effective collaboration.

We operationalize ambiguity, uncertainty, and confusion as follows. *Ambiguity* refers to a lack of sufficient or reliable information to fully characterize the situation and understand the possible outcomes [4]-[6]. *Uncertainty* refers to conditions where there are no definite outcomes; it could go one way or another [7]. Ambiguity involves not having enough information; uncertainty involves not having a clear answer regardless of the amount of information. While ambiguity and uncertainty are descriptors of the situation itself, they can cause *confusion*: an epistemic emotion and cognitive state of disequilibrium [8]. In other words, confusion is an emotional response to incongruency between prior and incoming knowledge that can't be immediately resolved [8].

Most engineering problems are not fully defined at the beginning, and while working toward the solution, engineers often encounter unanticipated constraints and obstacles, such as shipping delays, network outages, failed solutions, etc. [9]. Moreover, "workplace engineering problems often have multiple, often conflicting goals" [9, p. 108]. The evaluation of whether these goals are being met is commonly based on loosely defined, ever-changing non-engineering standards (e.g. client satisfaction as opposed to technical criteria) [9]. Likewise, in choosing a solution option, there are several complex factors to be considered and multiple viable paths to completion [9]. Lastly, unlike typical classroom questions, workplace problems usually do not have a previously determined answer [9]. From the uncertainty and ambiguity involved in solving these problems, engineers can experience discrepancies between what they already know and what they need to know, i.e., a knowledge gap, eliciting moments of confusion [7], [8].

One available resource for navigating confusion is collaboration. Studies show that pairs who work together construct shared mental models and knowledge pieces that neither individual may have previously held alone [10], [11]. As a result, collaboration creates an avenue for co-constructing new knowledge to address individual knowledge gaps. Beyond technical impact, team members' social moves can help regulate the emotions of the team at large [12]. This co-construction of knowledge and co-regulation of emotion fosters resolution of confusion.

Providing students with classroom activities reflective of professional engineering work - project-based, ambiguous, open-ended, and ill-structured - can help better prepare students for engineering practice [1]. It is expected for engineers to have the skillset of effectively working with others, regardless of experience, to complete the necessary tasks [13]. Since complex workplace problems involve grappling with AU&C [8], building collaboration skills and making confusion an accepted, manageable, and normal emotion in the classroom is essential [1].

II. Conceptual Framework

In this study, we seek to analyze moments of *productive engagement* with confusion. D'Mello et al. [8] explain how being confused doesn't directly lead to learning. Rather, through appropriately regulating confusion, students engage in deeper learning [8]. Engle and Conant loosely define Productive Disciplinary Engagement (PDE) as participation in the issues and practices of a discipline's discourse that yields significant progress from start to end [14], [15]. Looking at both conceptualizations, we define productive engagement as an interaction where students attempt to resolve confusion and make significant progress in learning by the end.

We use the construct of *Group Practice* to interpret the students' interactions. Medina and Stahl present a framework to analyze the team as a unit [16]. While we cannot directly observe individual mental models or directly experience an individual's cultural background, researchers can observe behaviors, interactions, and expressions on the scale of the group [16]. We acknowledge the contributions of each individual student, but in groups, each action is in relation to the prior and ongoing interactions of the team [16]. Furthermore, "contributions from two or more individuals [. . .] cannot be reduced to a mental achievement of either individual, or even a simple sum of their mental representations" since students continually respond to and elicit ideas from one another [16, p. 8]. Thus, Group Practice allows us to examine qualities of successful collaboration *in situ* instead of trying to predict group success from isolated individual behavior.

III. Methodology

Taken from video and audio recorded data from three teams across nine class sessions in an Introductory Computing for Engineering class, we report on an eighteen minute focal episode. The team consists of two students, Maeve and Leo, who have a good prior working relationship. They are studying SIR (susceptible- infected- recovered) models: an application of computational modeling and statistics to biology and disease analysis (see Appendix). We chose this episode because SIR models are traditionally confusing and the team showed productive engagement with the resulting confusion (as defined in section II).

We analyzed this episode using Braun and Clarke's six-step method of Thematic Analysis (TA) [17]. Before analysis, the first author transcribed the data using Sonix, followed by manual editing for accuracy and addition of gestures and tone. While not explicitly part of TA, the first author shared an episode analysis with a group of twelve other researchers participating in the larger project. The focus was solely describing and interpreting what happens. The twelve worked to reach convergence on observations, adding rigor to the analysis. Next, the first author focused on her reflexivity through familiarization. She then coded the data (latent and semantic) and grouped these codes to find preliminary themes. In future, we will refine these themes and create thematic maps. At this stage, we've developed two personas, three supporting preliminary themes, and one key insight. In this paper, we will discuss two themes and our key insight.

IV. Preliminary Results and Discussion

The research team of 12 members unanimously agreed that the pair productively navigates a confusing problem in a collaborative manner. This was confirmed independently by a separate group of the larger project team. Our data analysis reveals what patterns in the students' interactions contribute to this productive engagement with confusion in a team that defies the canonical norms of collaboration.

At first glance, we notice a pair where there is an imbalance in who is talking (see Fig. 1). Immediately, it appears one student dominates the conversation while cutting off the other's thoughts. This is contrary to common best practices which prioritize equal amounts of verbal contribution and active listening in teamwork. [3].

Leo: I don't get it. I'm trying to, like, do the same thing, like the size prints, but maybe it's like. because I'm doing like two, two times two, two by two.
Maeve: Yeah. Let's see if there's like a Matlab forum that tells us how to make tables. Those are usually helpful. Table crea... I can do it. Three tables and assign data to them. Okay. You can create a table from arrays by using the table function. For example, create a small table with data for five patients. Oh, wait. Okay. Okay. So this is what we're going to do. So a table. Just start with like our data point. So. Can you pull your ipad back out, sorry.
Leo: Yep.
Maeve: So basically we have to use like matrices instead of. Cause we know vectors. But we have to use matrices now. So what it's going to be. Wait one more time. I got to read this again. Okay. So the way we can do this is we can do. We can do: side name. Side name equals p N, like this. Then top name...or side 1 equals T. 98. 9603. Because if you want to make. If you want to make like like multiple rows. Cuz I figured this out the other day. I was just kind of playing around with it instead of like vectors where you put commas if you want it to be. It's a new line you get. You have to put like semicolons in there.

Fig. 1. An exchange between Maeve and Leo demonstrating Maeve's talkativeness.

Yet, as we account for the episode in full, Leo doesn't seem to be bothered by the outwardly unbalanced dynamic as evidenced by his continued engagement with Maeve. When we take a closer look at the nonverbal engagement, we see a different story (see Fig. 2).

Maeve: Okay. So the way we can do this is we can do. We can do [glances at Leo's ipad]: side name. Side name equals p N, like this. Then top name [glances at Leo's ipad]...or side 1 equals T. 98. 9603. [looking at Leo's ipad] Because if you want to make. If you want to make like like multiple rows. [Maeve scrolls on Leo's ipad]
Leo: [looks over to Maeve's screen]
Maeve: Cuz I figured this out the other day. I was just kind of playing around with it instead of like vectors where you put commas if you want it to be. It's a new line you get. You have to put like semicolons in there.
Leo: Hmm [Leo looks back to his screen]

Fig. 2. An example of the role of Leo's nonverbal communication

In this interaction, Leo's handwritten table of values on his iPad serves as a key resource for Maeve. Similarly, we see Leo actively looking at Maeve's screen and then going back to his own device to try to make sense of it himself. Eventually a bigger picture emerges where both students serve a necessary role in their interdependent sensemaking, even though one is more verbally articulate. This leads to our first theme: *collaboration entails joint sensemaking, verbal and nonverbal*.

In our analysis, we also saw patterns surrounding the impacts of emotional response. In Fig. 3 Maeve and Leo are willing to try things out that they aren't completely sure about, i.e., they navigate uncertainty. This interaction could have had other potential outcomes: (1) Maeve could have gotten frustrated; (2) Leo could have insisted they wait to figure out the logic first; or (3) they both could have given up. Instead, Maeve's social move of accepting contingency and Leo's validation of this move sets a norm that enables their productive engagement with confusion.

Maeve: Okay, true...This is not going to come out right. That's okay.
Leo: no worries

Fig. 3. Maeve and Leo setting the standard of mistakes being okay.

We notice a similar instance of emotional responsiveness in Fig. 4. At first, we had trouble making sense of Maeve's calm, nonreciprocal demeanor in response to Leo's frustration. However, we infer that this was a key social move to moving forward as it redirected Leo's frustration into action. Leo's frustration expresses where the confusion lies, and Maeve's redirection helps provide a resource for resolution.

Leo: I don't get it. [frustrated tone] I'm trying to, like, do the same thing, like the size prints, but maybe it's like. because I'm doing like two, two times two, two by two.
Maeve: Yeah. Let's see if there's like a MATLAB forum that tells us how to make tables. Those are usually helpful.

Fig. 4. Maeve redirects Leo's frustration.

In both of these moments, the core interaction was social rather than technical. Accordingly, we label our second theme: *emotional response and social moves influence learning*. In alignment with confusion being a cognitive state and an emotion, we see socioemotional responses directly promoting productive engagement with confusing engineering problems.

V. Conclusion and Future Directions

We observe a key insight that while Maeve and Leo don't follow championed collaborative practices, they establish their own norms and practices to make significant progress on a confusing engineering problem. Our analysis suggests that joint sensemaking, verbal and nonverbal, and attunement to each other's socioemotional responses are two features of Maeve and Leo's interactions that enable this productive engagement with moments of AU&C.

While currently limited by its observation of only two students, subsequent work will observe other groups from the same course at different points in the semester. Continuing to explore the role of both verbal and nonverbal communication in joint sensemaking can open new ways of productive participation in a team. Furthermore, the impact of emotional response can help us identify the core of what enables successful collaboration. Ultimately, the insight gained from real-time interactions between students rather than just individual best practices suggests an important theoretical orientation to support students in collaborative work.

Appendix: Slide of the Problem Posed in Class

Fig. A1 shows the presentation slide for the problem that the team worked on in this study.

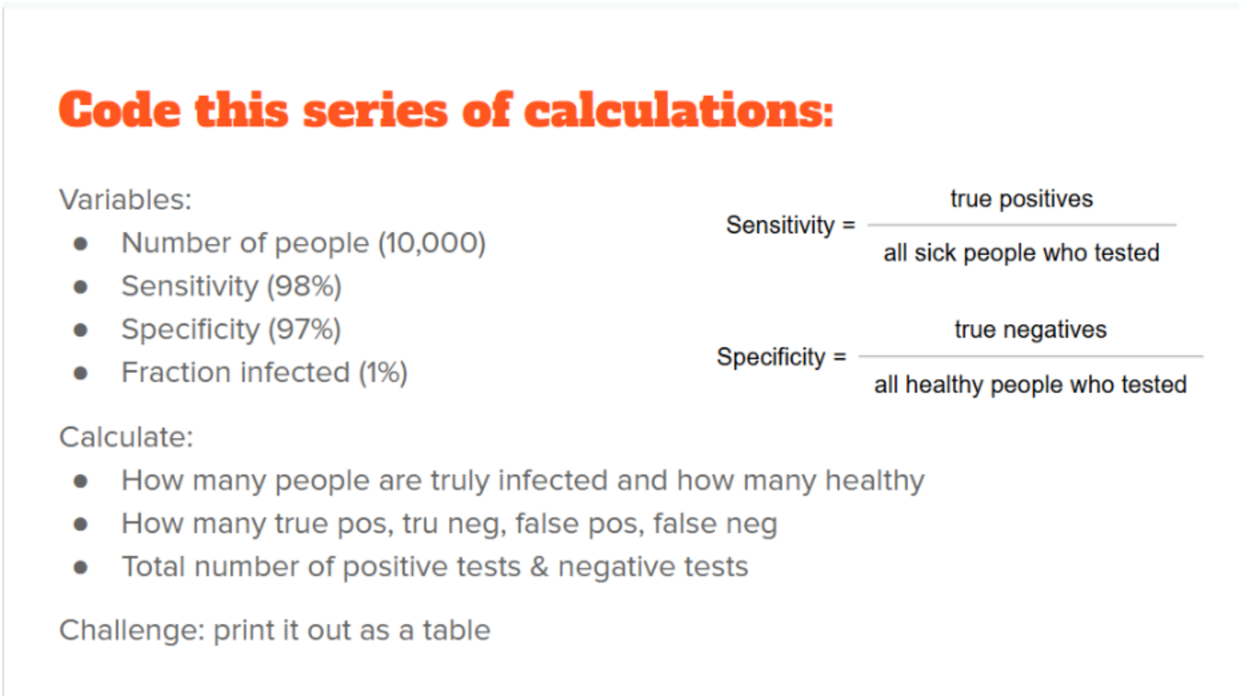

Fig. A1. Class slide for the activity being studied

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