Collaboration Conceptual Model to Inform the Development of Machine Learning Models Using Behavioral Analytics

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Objectives and Purposes

The world is becoming more digital and the current professional landscape increasingly requires competency in what were once considered "soft skills," like collaboration and communication (Van Laar, Van Deursen, Van Dijk, & De Haan, 2017). A report on employers' perspectives on necessary skills in the 21st century workplace ranked collaboration as the second most important prospective employee attribute (Lai, DiCerbo, & Foltz, 2017). Collaboration is a core teaching and learning process, as well as an important 21st-century skill that students must be able to master as they progress through school and into their careers (National Research Council [NRC], 2012). The Next Generation Science Standards (NGSS Lead States, 2013) and Common Core State Standards (CCSS Initiative, 2010) each call out collaboration as a practice required for successfully engaging in STEM fields.

K-12 classrooms consistently integrate collaboration as part of everyday learning experiences. In a typical classroom of 30 students, teachers are required to manage and assess how well approximately 10 groups of students collaborate as they work simultaneously (Cohen, 1994). Teachers generally do not have time to sufficiently listen to how well students are working together; they are highly reliant on what they can see as they make assessments on the quality of student collaboration. Furthermore, teachers incorporate the use of collaboration rubrics or peer surveys to gain additional insight about the quality of the collaboration, but due to a wide range of behavioral cues, it may be hard to determine specific behaviors that contribute to or detract from the collaboration effort (e.g., Taggar & Brown, 2001; Loughry, Ohland & Moore, 2007; Smith-Jentsch, Cannon-Bowers, Tannenbaum, & Salas, 2008).

We designed a conceptual model that organizes and structures various components of collaboration using specific behaviors that have been shown to be effective in collaborative groups. Non-verbal communication during instruction can show the intention of the sender of the information and even, in some cases, replace verbal communication (Bambaeeroo, & Shokrpour, 2017). Through our conceptual model, we created a set of codes using behavioral cues that can characterize the quality of individual contributions and the overall group interactions during collaboration. This conceptual model is then used with behavior-based learning analytics to train machine learning models to predict the quality of collaboration among small groups of students. The aim of machine learning models is to enable timely and useful feedback towards student development of collaboration skills and assist teachers in evaluation.

This work is not focused on student achievement or the outcomes of the collaboration, but instead on the *process* of collaboration: the behavioral interactions students engage in. We recognize that in collaborative settings, students are expected to self-regulate and take responsibility for their own learning, while teachers monitor and facilitate the learning (Tinzmann, Jones, Fennimore, Bakker, Fine, & Pierce, 1990), increasing the need for this type of tool that can allow students to self-assess during collaboration. This work is in its early stages of development and we have chosen to first focus on understanding student behavior during collaboration. Our current work seeks to answer the following research question related to our collaboration conceptual model: Can our collaboration conceptual model use behavioral cues alone to predict collaboration?

Perspectives: Developing the Collaboration Conceptual Model

Research has shown that face-to-face collaborative and cooperative learning is beneficial for students' learning (e.g., Bricker, Tanimoto, & Hunt, 1998; Slavin, 1991). In addition, students do not come to school already knowing how to collaborate and have productive conversations with other students (e.g., Johnson & Johnson, 2011). Collaboration is a skill that can be taught, practiced, and even mastered (Resta & Laferrière, 2007). In fact, the military has designed a very intricate way to use cognitive metrics to measure collaboration among adults in high stress situations (Noble, D., & Letsky, M., 2003). However, our work focuses on the secondary school context, impacting students who will enter a wide range of professions.

Defining collaboration. Some define collaboration in terms of the outcome it is meant to achieve. This could mean that collaboration is seen as a means to enhancing team performance (Gully, Incalcaterra, Joshi, & Beaubien, 2002; Mathieu, Maynard, Rapp, & Gilson, 2008; Salas, Cooke, & Rosen, 2008), learning of content, or developing problem solving skills (Kuhn, 2015). Others define collaboration as a way to share information (Swan, Shen, & Hiltz, 2006) or as the skill of guiding and leading others (Binkley, Erstad, Herman, Raizen, Ripley, Miller-Ricci, & Rumble, 2012). Still others define collaboration in terms of the behaviors or actions that make up the process of collaboration (Stevens & Campion, 1994) or in terms of the balance of participation among individuals (Bachour, Kaplan, & Dillenbourg, 2010). The mode of collaboration is another important factor in how collaboration takes place, with online and face-to-face collaboration making up the majority of collaborative environments and requiring different definitions and assessment paradigms.

Difficulties assessing collaboration. Differences in how collaboration is defined lead to differences in how it is assessed. Roschelle and Teasley (1995) offer a definition of collaboration as a "coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem." Further, collaboration skills and domain knowledge are not separate (Rotherham and Willingham, 2010), and the intertwining of content knowledge and skills (e.g., collaboration) supports transfer of learning to new contexts (Pellegrino & Hilton, 2012). When assessing students on a skill, like collaboration, the constructs being assessed must be identifiable (Pellegrino, Chudowsky, & Glaser, 2001). However, because there are various ways collaboration is defined and described, identifying the constructs to assess is difficult. Another difficulty for assessment is the complexity of interactions that come together to become a collaborative interaction, making the constructs being measured elusive.

To assess collaboration using behaviors, we must determine what counts for each type of behavior; for example, what does off-task behavior (Godwin, K., Almeda, V., Petroccia, M., Baker, R., & Fisher, A., 2013) or agreement and disagreement (Bousmalis, K., Mehu, M., & Pantic, M., 2009, September) look like? We need to better understand and identify the behaviors that are associated with good collaborative learning, how those behaviors are organized, and how they lead to a collaboration session.

Collaboration conceptual model. Our work deconstructs various research and collaboration rubrics in different settings to develop a conceptual model for collaboration (see Figure 1 and Table 1) that can be used to assess student collaboration. We analyze collaboration using individual student behaviors (Levels C, D) as well as overall collaboration and participation structures (Levels A, B). Our unit of analysis is at both the individual and group levels, since individual behaviors impact group behavior and overall collaboration.

Methods, Techniques, and Data Sources

Collaboration context. In the spring of 2019, we conducted a small pilot data collection in five middle schools with eight teachers and sixty students. We visited each classroom up to 3 times in a lab setting after school. Students completed a brief survey that collected information about their comfort levels with collaboration and different life science concepts, and demographic information (e.g., languages spoken, ethnicity). We videotaped and audio recorded one group at a time.

The collaboration task. Students worked collaboratively to create models or solve 12 open-ended life science and physical science tasks. We used short, structured tasks to localize student behaviors.

Recording set-up. We collected data by positioning three Microsoft kinect cameras in a triangular configuration around groups of four students sitting in a shape of a U around a table (see Figure 2). The data recording software combined, synchronized and calibrated the images from the cameras to create a 3D view for accurate behavior analytics.

Data segmentation and collaboration level descriptions. Each video recording was segmented by task prior to being coded by human annotators with a maximum of 12 segments per video. Collaboration tasks could range from 5 to 25 minutes each. Video recordings were also separated into two modalities, (1) impoverished modality (visual only), and (2) full modality (visual and audio). Videos were then manually annotated, level by level, by seven education researchers in the impoverished modality. The full modality will be coded after the impoverished to prevent bias. As shown in Figure 1, the collaboration annotations depend on a combination of complex behavioral interactions of intellectual contribution to the group work, and not one indicator.

Our Multimodal Integrated Behavior Analysis (MIBA) software extracts low level tracking of human head-pose, eye gaze, facial expressions, body-pose and gestures in Level E (Figure 3). The low-level features from Level E are used to generate Level D descriptors like joint attention and engagement. The Level D descriptors are used to describe more complex interactions, such as “sharing tools” or “explaining ideas”, in Level C. Complex behaviors from Level C are used to determine the individual roles of each student, such as “follower” or “group guide” in Level B2, and group dynamics like “social and hyperactive” in Level B1. All levels intricately come together as an overall collaboration code, such as effective or progressing in Level A.

Determining reliability. To establish interrater reliability (IRR), the human coders participated in multiple training sessions over approximately 3 months. The training served as a space for developing a shared meaning of the codes and more detailed criteria for each code. The human coders watched the videos task by task as a group, verbalizing their interpretation of the students’ interactions starting with the coarse-grained levels of codes (A and B) and moving to the fine grained levels of codes (C and D). The process was iterative, where decisions made during the training session were recorded and used to refine a shared coding scheme for individual coding. After training, each video will be independently coded 3 times to account for annotation bias.

Initial Findings

Student surveys showed that 50% of all participating students perceived themselves as very comfortable with collaboration, while there was mixed comfort with the science concepts. Additionally, due to the voluntary nature of our recruitment process, data is biased towards students that identify as Asian and male. Our initial work with the MIBA system shows successful calibration and synchronization of high-quality information from audiovisual and sensory input (see Figure 3). Using MIBA, the collaboration conceptual model has the ability to capture behavioral cues associated with collaboration, but annotation cues continue to be refined to provide clear indicators for collaboration behaviors. Through IRR discussions, each code is being polished to increase accuracy and agreement in behavior identification. Currently, Cohen’s Kappa IRR for impoverished coding of levels A and B is between 0.3 and 0.4 and our goal is to reach at least 0.6 for Kappa IRR for all levels (A-D).

Next steps. After applying our collaboration conceptual model to both impoverished and full modalities, we will analyze whether behavioral cues alone (impoverished modality) have the same predictive power for collaboration as verbal and behavioral cues (full modality). In later stages of this work, we will determine whether the machine learning model performance based on full modality (verbal and behavioral cues) and impoverished modality (behavioral cues only) coding performs better than chance.

Scholarly Significance of the Work

This work will contribute to the research that points to collaboration as a fundamentally important skill that can be measured and developed. This study is designed to increase knowledge about how human behaviors combine into complex interactions that lead to collaboration. This work also aims to increase our understanding of how to use automated tracking systems to identify collaborative behaviors that align to a collaboration conceptual model. This work will benefit students by making self- assessment feasible and will help teachers support students in collaboration sessions at the individual and group levels. The eventual video-based analytics and machine learning can change how we collect data on classroom interactions and the future landscape of such research, providing a new understanding of collaboration and other interpersonal interactions in learning spaces.

References

Bambaeeroo, F., & Shokrpour, N. (2017). The impact of the teachers' non-verbal communication on success in teaching. Journal of advances in medical education & professionalism, 5(2), 51.

Bousmalis, K., Mehu, M., & Pantic, M. (2009, September). Spotting agreement and disagreement: A survey of nonverbal audiovisual cues and tools. In *2009 3rd international conference on affective computing and intelligent interaction and workshops* (pp. 1-9). IEEE.

Bricker, L., Tanimoto, S., & Hunt, E. (1998). Effects of cooperative interactions on verbal communication. *Paper submitted to ACM CHI*, *99*.

Common Core State Standards Initiative. (2010). Common Core State Standards for English language arts & literacy in history/social studies, science, and technical subjects. Retrieved from http://www.corestandards.org/ELA-Literacy/

Godwin, K., Almeda, V., Petroccia, M., Baker, R., & Fisher, A. (2013). Classroom activities and off-task behavior in elementary school children. In *Proceedings of the Annual Meeting of the Cognitive Science Society* (Vol. 35, No. 35).

Johnson, D. W., & Johnson, R. T. (2011). Cooperative learning. *The Encyclopedia of Peace Psychology*.

Lai, E., DiCerbo, K., & Foltz, P. (2017). Skills for Today: What We Know about Teaching and Assessing Collaboration. *Pearson*.

Loughry, M., Ohland, M., & Moore, D. (2007). Development of a theory-based assessment of team member effectiveness. Educational and Psychological Measurement, 67(3), 505–24.

National Research Council (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academies Press.

NGSS Lead States (2013). *Next Generation Science Standards: For states, by states.* Washington, DC: The National Academies Press.

Noble, D., & Letsky, M. (2003). Cognitive-based metrics to evaluate collaboration effectiveness. EVIDENCE BASED RESEARCH INC VIENNA VA.

Pellegrino, J. W., Chudowsky, N., & Glaser, R. (2001). *Knowing what students know: The science and design of educational assessment*. National Academy Press, 2102 Constitutions Avenue, NW, Lockbox 285, Washington, DC 20055.

Pellegrino, J. W., & Hilton, M. L. (2012). Committee on defining deeper learning and 21st century skills. *Center for Education*.

Resta, P., & Laferrière, T. (2007). Technology in support of collaborative learning. *Educational Psychology Review*, *19*(1), 65-83.

Roschelle, J., & Teasley, S. D. (1995). The construction of shared knowledge in collaborative problem solving. In *Computer supported collaborative learning* (pp. 69-97). Springer, Berlin, Heidelberg.

Rotherham, A. J., & Willingham, D. T. (2010). 21st-century" skills. *American Educator*, *17*(1), 17-20.
Slavin, R. E. (1991). Synthesis of research of cooperative learning. *Educational leadership*, *48*(5), 71-82.
Smith-Jentsch, K. A., Cannon-Bowers, J. A., Tannenbaum, S. I., & Salas, E. (2008). Guided team self-correction: Impacts on team mental models, processes and effectiveness. Small Group Research, 39(3), 303–327.
Taggar, S., & Brown, T. C. (2001). Problem-solving team behaviors: Development and validation of BOS and a hierarchical factor structure. Small Group Research, 32(6), 698–726.
Tinzmann, M. B., Jones, B. F., Fennimore, T. F., Bakker, J., Fine, C., & Pierce, J. (1990). What is the collaborative classroom. *Proceedings of NCREL*.
Van Laar, E., Van Deursen, A. J., Van Dijk, J. A., & De Haan, J. (2017). The relation between 21st-century skills and digital skills: A systematic literature review. *Computers in human behavior*, *72*, 577-588.

Figures and Tables

Figure 1: Conceptual model for collaboration

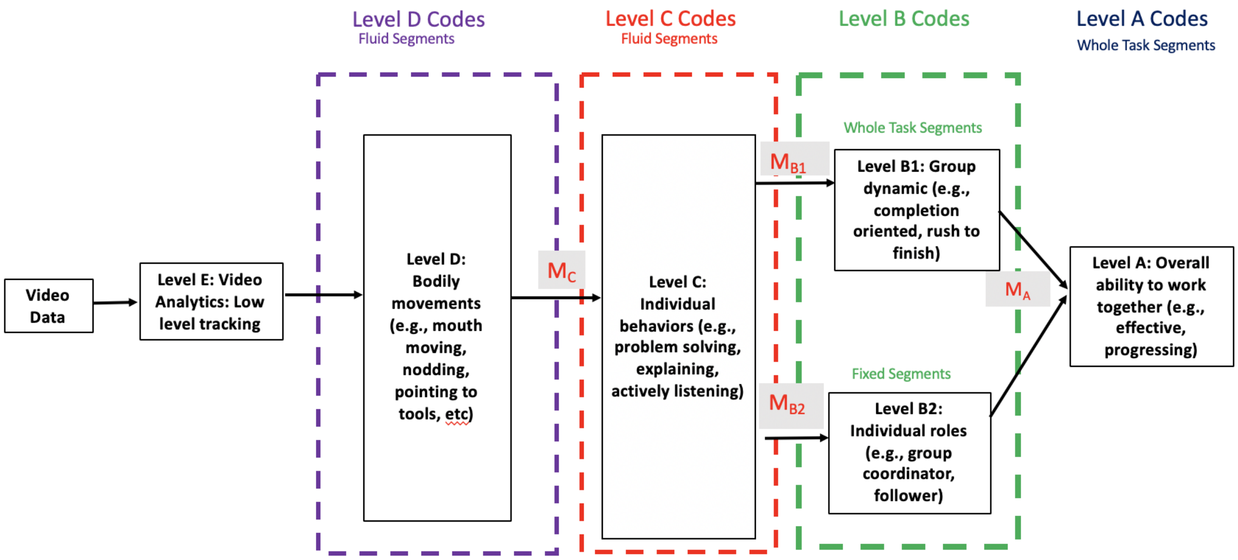

Figure 2: Diagram of collaborative seating arrangements

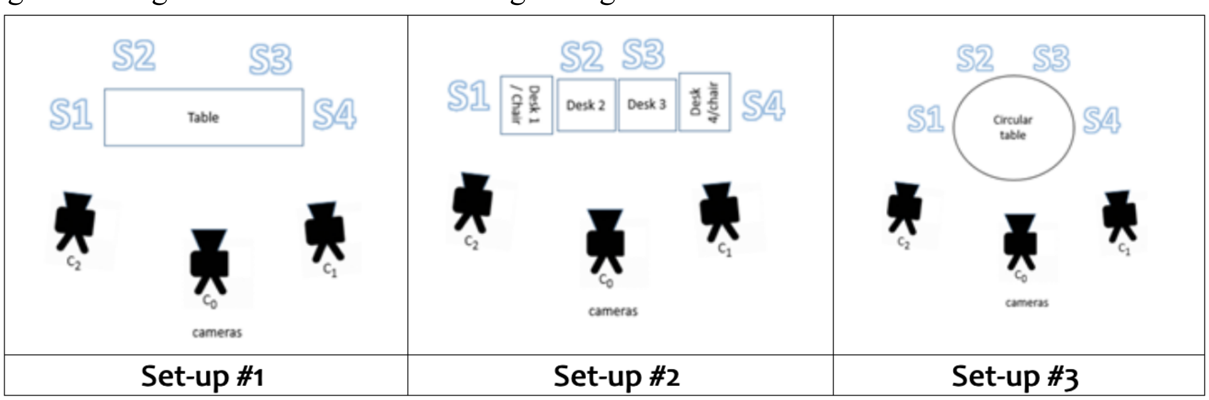

Figure 3: Annotation process using conceptual model and behavior codes

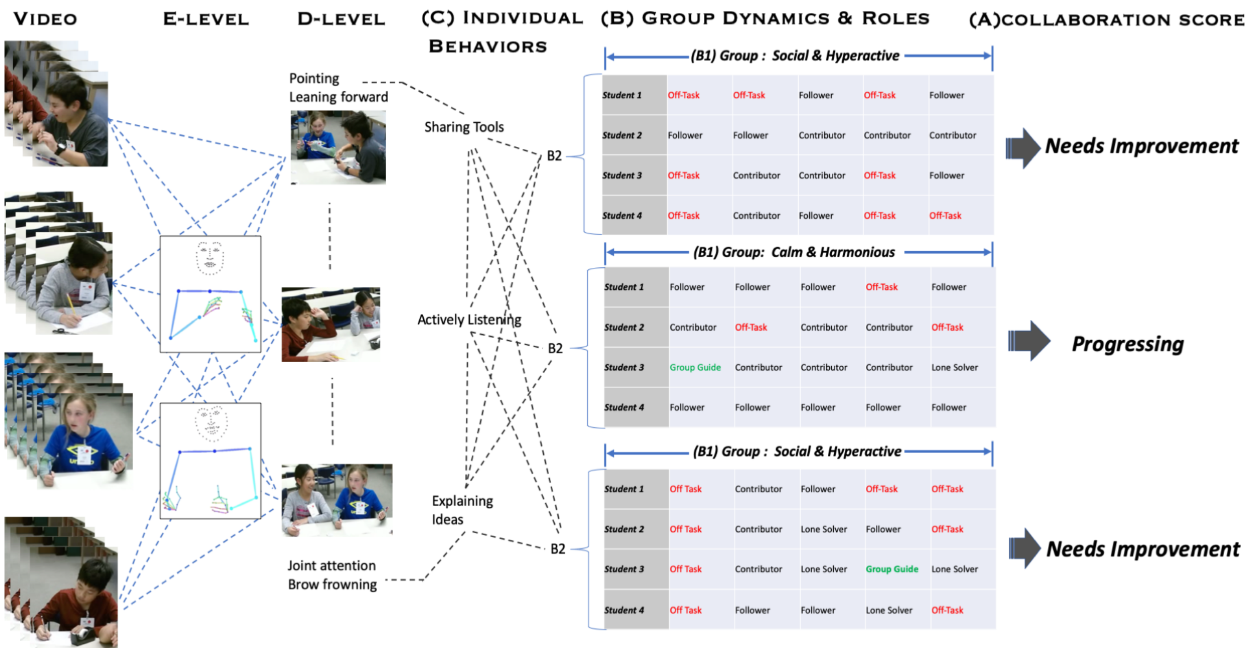

Table 1: Example behavioral codes

Level	**Description**
A: Overall collaboration quality	•Effective •Satisfactory •Progressing •Needs Improvement •Working independently
B: B1-Group dynamics B2-Individual participation and contribution roles	B1: •Rush to finish •Social and hyperactive •Everyone is working independently •Contentious and argumentative •Blasé/ Disinterested •Focused/ studious •Calm and harmonious •1 person dominates/ Fighting for control •Completion oriented B2: •Group guide/ Coordinator

	•Contributor (Active) •Follower (Passive/going along for the ride) •Conflict instigator/Disagreeable •Off-task/Disinterested •Lone solver (selfish, narcissist, etc) •Conflict resolver
C: Individual complex behaviors	•Recognizing/inviting other contributions •Setting group roles and responsibilities •Comforting others/ encouraging others/ corralling •Agreeing •Off task/Distracted •Disagreeing •Joking
D: Low level behaviors	•Mouth moving •Nodding •Leaning forward •Looking away •Leaning backwards •High-five •Looking at each other •Smiling •Laughing •Using pen/pencil •Moving paper manipulatives •Moving packet around •Passing materials •Moving bodies •Moving chairs •Moving table