COMMUNICATION IN STEM EDUCATION: A NON-INTRUSIVE METHOD FOR ASSESSMENT & K20 EDUCATOR FEEDBACK

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Abstract

The current push to educate highly qualified and productive Science, Technology, Engineering and Mathematics (STEM) professionals typically culminates in collegiate capstone projects. These group projects attempt to prepare STEM professionals for entry into the real world as they exemplify early career group dynamics and expose the reality that communication and other soft-skills are often just as important as technical skills. Since attitudes of STEM students and early career professions are established throughout the entire K-20 curriculum, this article also provides some feedback to educators. The research presented utilized, a free cloud based collaboration tool to observe the communication habits of three senior capstone teams (n= 13 participants) and was able to predict communication success and failures through straight-forward analysis of several key parameters, including: discussion frequency, number of responses and the distribution of work over time.
Key words: *communication in STEM, communication assessment, senior capstones, non-intrusive soft-skill assessment, engineering education, ABET.*

Introduction

A gross misconception exists amongst many K20 science, mathematics, engineering and technology (STEM) students – and the only way to eliminate it is by educating our students in a soft skill they are trying to avoid. Many future and current STEM students believe that their future career will only require a single technical skill set. Unfortunately, soft skills, such as effective communication – are the cornerstone of every successful STEM practitioner, researcher, and educator. The only way to address this communication gap is by teaching our current K20 students these soft-skills. Unfortunately, assessing student gains in soft-skill is a non-trivial task. There is no test for how well one communicates. The ability to communicate is generally only assessed through observation – a task that is not only tedious, but also biased and skewed when done in controlled environments (e.g., a classroom presentation). This paper focuses on an approach for unobtrusive observation of communication within teams and then demonstrates how objective measures can predict and align to observable communication successes and failures.

Problem of Research

Communication is a critical component in creating well-rounded STEM citizens (Mellors-Bourne, Connor & Jackson, 2011; Carnevale, Smith, & Melton, 2011). Effective communication impacts careers, teams, businesses and collaborations and in a larger scope – how we as a people make public policy decisions. This work is grounded in three key aspects of communication and education; first and foremost, the importance of communication in STEM education; secondly, existing methods and practices for the integration of communication into

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K-20 educational practices; and finally, the current state of assessing communication competency in K-20.

Importance of Communication

The importance of communication within STEM education is steeped in existing literature. Students who are ultimately successful are not only problem solvers with highly technical skill-sets, but also are effective at communication, collaboration, and understand the relationships between society and science (Brewer & Smith, 2011). The complexities of integrating STEM and communication, according to Davis, Beyerlein, and Davis (2005) are due to “misguided or mismatched understandings” of what high-quality performance actually means for practicing engineering professionals. Davis et al. (2006) highlight four areas that capture future STEM related professional performance; two of the areas deal with soft-skills, including communication, in both a personal capacity as well as in team-processes. These skills, they claim, “support technically sound and responsible design.” With team-oriented practices at the cornerstone of industry and academia, it’s critical to note that the top three common difficulties detected during team-based projects are manifestations of communication issues. These issues range from the obvious “poor communication among members” to higher-level applied communication issues of “poor leadership” and “failure to compromise” (Dutson, Todd, Magleby & Sorensen, 1997, p. 24). Communication, and other soft skills are so critical, that of the eleven student outcomes which the Accreditation Board for Engineering and Technology (ABET) requires engineering programs to show evidence of, only five relate to technical abilities, while the remaining six focus on soft skills (Williams, 2001). While highlighting the importance of communication grounds in this work, it is important to understand that K-20 education practices already incorporate a variety of communication centric approaches. Unfortunately, important workplace soft-skills such as teamwork and communication receive “relatively little attention from the engineering education research community” (Singer & Schweingruber 2012).

Communication in K-20

A variety of approaches, from specific methods to entire curriculums, already exist in K-20 classrooms to build and develop the communication skills of students. The newly created Next Generation Science Standards propose that science education requires students to develop explanations, evidence-based arguments, discuss open-ended questions, and engage in discussions (National Research Council, 2015). Several universities have created minors in Engineering Communication and Performance in order to provide formal training in “performance skill’s necessary for success” with an objective of making their engineering graduates “effective communicators” and “socially adept” (Seat, Parsons & Poppen, 2001, p. 7). While STEM lecture-based courses have been paired with laboratory style course, a recent shift in practice enhances laboratory experience with collaborative learning in order to engage student driven discussion throughout group work, short-term projects and full-term design projects (Gol & Nafalski, 2007). Irrespective of a specific course, curriculum or grade level, a common method of engaging students in non-rote exercises is through Problem Based Learning (PBL) activities. Savage, Chen, and Vanasupa (2007) highlight that one of the key elements for successful PBL activities is that “team building exercises should be utilized to facilitate the development of trust and communication within the team” (p. 5). These activities are exemplified in culminating, baccalaureate terminal courses, required by many STEM disciplines. These courses are often referred to as senior capstones, or senior design projects. A 2004 national study of STEM capstone courses found that 88% of respondents’ capstone projects were team-centric (McKenzie, 2004). With over two decades of communication focused curriculums and methods used in K-20 classrooms and still a perception that young STEM professionals are ill prepared to communicate – our assessment of STEM students’ communication skills must be addressed.

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Assessment of Communication

While assignments, courses, instructors, curriculums and accreditation boards have specific target outcomes and objectives related to communication, the question of how to accurately gather evidence and assess student gains remains loosely defined within the STEM disciplines. Gotel, Scharff and Seng (2006) describe a course in which communication was a critical component and those activities were "recorded using a weekly questionnaire" (p. 11) that was meant to examine details about communication participants, topic, frequency, timing and co-location. Their findings on communication focus on the models, mode, intensity and topics of communication, but when looking at the lessons for education and practice no clear assessment methods were identified. While literature on assessing STEM communication is limited, some work has begun in creating active listening skill assessments (Wilkins, Bernstein, Harrison, Bekki, & Atkinson, 2011). Wilkins et al. developed a 42-item instrument to measure STEM student's knowledge, ability and self-efficacy with respect to active listening. By their own admission, no formal observation of the student's actual ability was measured since "actual observations can be costly and time intensive." Assessing data collected from surveys, focus groups and student deliverables, a northwestern American university redesigned their capstone program with added emphasis on student learning and application of "project management, time management, teamwork, and communication skills" (Faust, Greenberg, & Pejcinovic, 2012, p. 1). The findings of Faust et al. (2012) also point to a disconnect between self and external assessments of team cohesion – with external assessors unable to detect the lower performing groups.

Research Focus

This research highlights a mechanism to capture and assess team communication dynamics without relying directly on participant perceptions. Rather, this work uses statistics, trends, unprompted question and answer (Q&A) forums and documents captured through a free, online, distributed version control system. This approach provides not only a first pass at an objective and quantitative view of individual and team communication, but also the ability to use artifacts as qualitative support.

Methodology of Research

General Background of Research

The research study presented here focuses on two types of data – quantitative data that was directly collected from an existing cloud-based collaborative version control tool as well as qualitative data stored within the same system. This mixed method study focused on three unique capstone projects occurring either during the 2013-2014 or 2014-2015 academic years. The capstone projects within this study were conducted at an American university with whom the researcher has no direct affiliation. The study participants consist of senior engineering students within the three separate teams. The study looked at the interactions between the participants themselves, an academic advisor assigned to each team, and an external sponsor for each team. The researcher used the following two questions in guiding the development and execution of the study:

1. How can the communication of senior capstone teams be assessed?
2. How can the communication of senior capstone teams inform K20 educators?

Using these questions as a foundation, the researcher first examined communication frequency, engagement and depth through analysis of well-defined numerical metrics. The researcher then coded communications and non-technical documents produced by the team to determine any underlying patterns. A follow-up survey was requested and completed by a subset of the participants (n=9). The researcher used the per-group completion percentage of the survey to validate any correlation between underlying communication patterns detected in the open response coding and the purely analytical processing of the numerical metrics.

Sample of Research

The participant sample in this study contains three groups of senior students studying Computer Science & Engineering at a single American university during the 2013/2014 and 2014/2015 academic years that interacted with three academic instructors and two project sponsors. The total participant sample of 17 consisted of the 12 undergraduate students, three instructors, and the two project sponsors. Of the total participant sample, there were three females – one instructor, one student, and one sponsor. The three student groups were all assessed using the same methods and procedures after collecting data in an identical fashion during both academic years. For simplicity and anonymity, the three groups will only be identified as groups Ada, Bohr and Curie; individual students within the groups will not be identified.

Instrument and Procedures

In order to reduce complexity of reuse by future researchers and instructors, a single online cloud-based tool was used to capture a majority of both the quantitative and qualitative data. Unlike traditional assessment instruments, the researcher re-purposed an existing online collaborative tool in order to transparently collect data without interfering with the workflow or habit of the senior capstone teams. For this particular study, the researcher used a version control and project management tool called git. Version control systems give users the ability to save work and see exact changes over time, and if needed, revert parts and pieces or entire documents back to a previous version. Specially, the capstone sponsor requested that each capstone team used github, a cloud-based instance of the git tool that contains additional collaborative features. The additional features of github that were used included the ability to create a wiki – or an online journal, and "open issues" when question or problems were found. At the beginning of the capstone project, all student participants were asked to use the tool as a centralized location for all development work, deliverables, meeting notes and questions both internal to the group as well as externally to project sponsors. In order to remove any bias from the researcher and sponsor, data from the tool was only downloaded and analyzed after the conclusion of the capstone project experience. In addition to the use of the tool, participants were also asked at both the beginning and end of the project to complete a 20-minute open response survey – the study presented here only uses data related to the response rate per team.

Data Analysis

The cloud based tool used in this work allows insight into several numerical parameters, key to communication, including, with respect to a particular individual: number of emails sent, number of discussions started, number of discussions responses, length of each discussion thread and workload trends (when work was added to the cloud based tool). Additionally, the researcher identified the distribution of committed work over time, as well as the use of other collaborative features within the tool. The researcher then collected information on the number of meetings that teams held – identifying if they were team member only meetings or with the sponsor as well. Additionally, the number of responses to a pre and post survey was collected and normalized over the number of participants in a given group. Finally, the participants' weekly reports were coded for communication topics. In total, this research presents findings surrounding 11 quantifiable metrics.

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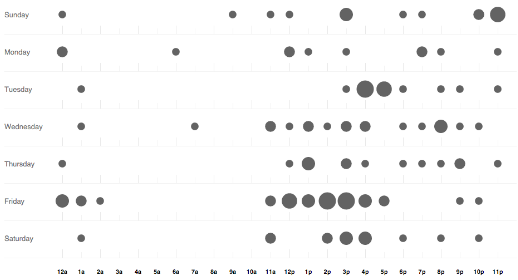
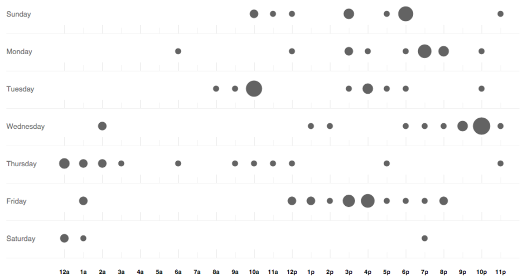
Results of Research

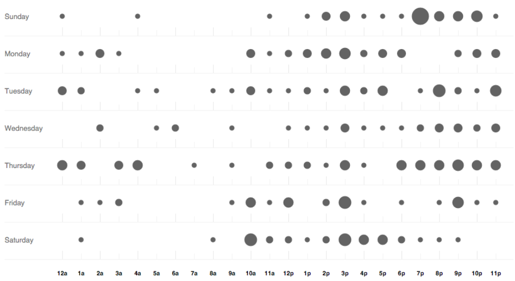
While a total of 11 quantifiable metrics were collected, four were based on the researchers' observations, while the remaining seven were collected through the cloud based collaboration tool. The four metrics collected "by-hand" are the ones that would typically be used to gauge communication and focus on meeting frequency and team engagement. The tool allowed the researcher to capture seven quantifiable metrics surrounding communication without any inference, bias or intrusion into the team dynamics. The captured metric ranged from the number of discussions (email, online and total); the average length of each discussion – as measured by the number of responses; how work was distributed based on day of the week and time of day; what the work frequency of the group appeared to be over time; and finally, whether or not the team took advantage of collaborative features within the online tool. In order to quantify the work distribution and work overtime, the researcher used the charts shown in Figure 1 to classify work distribution as either evenly spread over time (Ada and Curie) or unevenly (Bohr). More specifically, note that the Ada and Curie teams have an evenly distributed work schedule across all days afternoon and into early morning, while the Bohr team has a wider variance of submitted work. Figure 2 shows the charts used by the researcher to quantify the pattern of work as increasing (Ada and Curie) or decreasing (Bohr).



(a) Ada



(b) Bohr



(c) Curie

Figure 1: Comparison of work distribution for three teams. Each row is a day of the week; each column is an hour during the day. The size of each circle represents a normalized view of work submitted during the day and hour combination.

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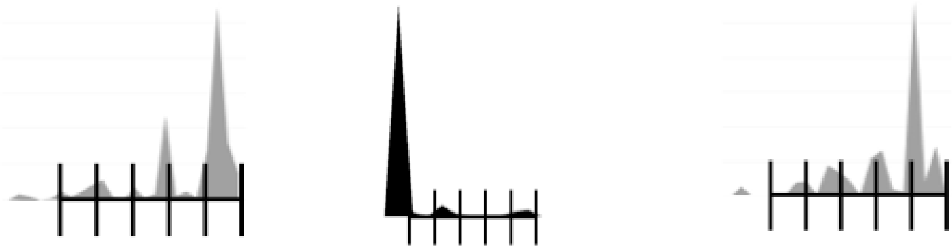

a) Ada b) Bohr c) Curie

Figure 2: Comparison of pattern of work over time for three teams over a 6-month period: (a) Ada, (b) Bohr and (c) Curie. Each tick mark represents the end of a month.

Table 1 shows an aggregated view of the 11 quantifiable metrics for the three participant groups in this study. The first seven metrics (1-7) are directly taken from the online tool, while the last four (8-11) are derived from the researchers observation of group interactions. The 11 quantifiable results mirror the data collected and include in order: 1) the number of email discussion of the group, 2) the number of online discussion carried out by the discussion, 3) the total number of discussions, 4) the length of the discussion (as measured by the number of replies to a discussion thread), 5) how evenly distributed was the work (based on classification of Figure 1 data), 6) the work frequency over time (based on classification of Figure 2 data), 7) whether or not teams used additional collaborative tools, 8) the number of team meeting with the sponsor, 9) the number of meeting without the sponsor, 10) the total number of meetings and finally, 11) the percentage of the team responding to a post-survey.

Immediately the Bohr participant group stands out with low marks in the metrics derived from the online tool – low total number of sponsor visible discussions, uneven work frequency and lack of collaborative tool usage. When comparing these metrics to the other four quantitative metrics we easily see that this group also has low marks in meeting with each other and the sponsor – with the team also only having a 33% response percentage to the pre and post survey. While the two remaining groups are more evenly paired, it is interesting to note that the Curie team did not utilize the additional collaborative features supplied by the online tool– rather, they supplemented communication through the use of email and additional sponsor meetings.

Table 1. The eleven quantifiable metrics for three teams: bolded items indicate the highest unique value in a category while those italicized are the lowest unique value.

		Participant Teams		
	Topic	**Ada**	*Bohr*	Curie
Tool Based Metrics	Email Discussions	16	*9*	**56**
	Online Discussions	**96**	4	*0*
	Total Discussions*	**112**	*13*	56
	Avg. Discussion Length	**4.9**	*1.9*	3.4
	Even Distribution of Work	Yes	*No*	Yes
	Work Over Time	Increasing	*Decreasing*	Increasing
	Use of Collaborative Features	**Yes**	No	No
Observed Metrics	Sponsor + Team Meeting	6	*2*	**9**
	Team Meetings	20	*8*	20
	Total Meetings	26	*10*	**29**
	Responded to Survey	80%	*33%*	**100%**

Themes in Artifacts

When coding documents from Ada, a theme of *expert pairs* emerged where any issues were discussed in small collaborative pairings then brought to the larger group for suggestions and input. The team also regularly communicated what they had done, what they were planning on doing and what issues they currently had –with respect to the project as well as in the other academic and personal endeavors. The Bohr team also submitted weekly-based status reports, but they were less natural, and ended well before the conclusion of the term. From the early status reports, though past the midway of the term comments within the documents such as "teammate refused to …" were prevalent across several team members. Additionally, meeting minutes pointed out advice from their academic advisors to "have regular [weekly] meetings." The general theme that emerged from the Bohr documents was one of *disconnected experts* who had trouble establishing any regular pattern of communication. Finally, the Curie team created collaborative follow-up documents after each meeting – as a smaller sized team each member became a content expert, but determined and communicated as a team – their documents were filled with "[member_X] has volunteered to take lead on …" and "[member_Y] and [member_Z] have shared … with the rest of the team."

Discussion

Recall the two driving questions for this research. The first dealt with assessment of communication in capstone teams, while the second surrounded using capstone communication trends to inform K20 educators. In regards to the first question – when separating out the major themes from each group it was apparent that there were two groups, Ada and Curie, that were communicating and in sync, while the Bohr group failed to establish a routine that would allow them to communicate effectively. Using the last four observed metrics from Table 1, which follow typical communication observation metrics, a pattern of collaboration and communication was easily identified - with the Ada and Curie teams meeting two and half to almost three times more than the Bohr team. Next, when analyzing the seven tool based metrics, the Ada group clearly stands out in the number of online discussion as well as the length of each discussion and the distribution of work. The longer discussion lengths of the Ada and Currie team implies non-trivial collaboration with deeper and richer conversations which is in contrast to the shorter length of discussion within the Bohr team – with most discussions being a single question associated with a single response. Furthermore, the even distribution of when work occurred for the Ada and Curie teams suggests that both of these teams were able to align themselves on common work and collaboration schedules – a critical key for effective communication. Established within the research study were clear patterns of behavior present in easily quantifiable metrics of communication frequency, discussion length and distribution of work over time. Future work is needed in increasing the sample size of the study, defining the interpretations of the distribution of work and the work over time metrics as well as more in-depth coding and analysis of artifact themes.

While a relationship exists between the seven tool-based metrics and the four observed metrics in their ability to measure communication in capstone teams, the feedback for K20 educators is perhaps more subtle. While there are clear communication successes, it is currently more difficult to attribute success to specific K20 practices; as such the focus of this discussion is on the observable root cause to the communication issues. In this vein, the Bohr team had resource conflicts (of time) and identity conflicts (between team members), which impeded their ability to communicate – not only with themselves, but with their sponsor and academic advisor as well. K20 educators can enhance their group-based projects by injecting benign conflicts into their scenarios – giving students exposure to solving these types of issues early in their education. Furthermore, effective communication within a team does not immediately translate to effective communication outside of the team – K20 educator can promote internal team communication as well as team to "assessor" communication – mirroring real world instances in which a team is always judged by some outside or higher-level entity. Finally, a note about richness of communication – a key parameter of effective communication hinges on the ability to have continuous refinement during a Q&A session. The three groups in question had varying levels of success in this area – with Ada having Q&A discussions with an average of five interactions, while the Bohr team only had 1.9 interactions per session. Focus and attention to effective questioning (and active listening) are critical to enhancing team dynamics.

Conclusions

The goal of this study was to determine if the communication patterns and abilities detected in the weekly reports, survey completion and meeting frequency could be predicted from the data collected using a cloud based collaboration tool. When looking at the three senior capstone groups within the study, two groupings clearly emerged – two who communicated well and one that did not. The data presented supports the ability to detect communication abilities or issues through analysis of built in metrics for a common STEM based collaboration tool. While future research is needed, current K20 teachers can build upon the work here as a first pass to detecting communication issues within groups – whether it is an elementary classroom PBL project or a senior capstone – by looking for the length of conversations in terms of the number of interactions, team dynamics, and the pattern of when work is produced. Purely data driven decisions are not always possible – but for group-based communication, given the right tools, we can gain incredible, quantifying insights without having to rely on the perceptions of those we are trying to assess.

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