Preparing globally competent and competitive STEM workforce of the 21st century in the Global STEM Classroom®

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Abstract

Technological advancements over the last decade have dramatically changed the reality of the STEM professional world, the way STEM professionals work, and the skills that are now required. One of the major changes is that STEM professionals are working in teams, generally multicultural teams in the United States or global teams collaborating through technology. Today's students—tomorrow's workers— without ability to learn and work with people from diverse cultural backgrounds, and skills to function productively in an interdependent world community will not be able to improve the United States' economic competitiveness, and provide leadership in innovation and creativity. The Global-STEM Classroom® reflects these rapid changes, addresses the new skill requirements, and provides innovative technology experiences for students and teachers by modeling authentic, multi-cultural, multi-disciplinary collaborative, STEM professional teamwork processes.

The Global STEM Education Center, Inc 501 (c) (3) nonprofit founded in 2008 with a mission to "increase participation in STEM disciplines by all students and, especially girls and students from underrepresented groups, to meet the needs of an innovation-driven globally competitive workforce". It involves a collaborative learning environment specific to Science, Technology, Engineering, and Math (STEM) projects. The Global STEM Classroom® implies creating virtual environment of one joint classroom where students from two or more schools in different countries receive instructions from one teacher as if they are in the same classroom (using both synchronous and asynchronous teaching and learning approaches). The participating schools are located in the United States, United Kingdom, France, Russia, Ukraine, Mexico, Norway and the Netherlands (Australia, Ireland, India will be joining next academic year). The Global STEM Classroom® program specifically addresses secondary education with students ages 12-17 years old (more than 50% girls and students from underrepresented groups) giving students a learning advantage in preparation for higher education, raising an awareness of and "sparks" the interest in engineering professional and studying STEM disciplines and expands cultural and technical competency for the global workforce. The Global STEM Classroom® participants typically complete real-life STEM (both research and hands-on) projects with an online virtual global student team. The present study was undertaken to answer the following research question: *What are the attitudinal effects of participation the Global STEM Classroom® in terms of students' motivation for participation, levels of engagement, and interest in continuing to participate in similar projects?* The research model was a within-group, change-over-time model and data collection relied largely upon pre-post survey findings to determine whether the Global STEM Classroom® was effective at meeting its declared objectives. The methods included an extensive online survey comprising the constructs embedded in the research question. Findings from the survey showed that:

- Students chose to participate because they were motivated by the content, the possibility of collaborating internationally, or because they thought it would be good for their academic and future careers.
- Students most enjoyed the interactive aspects of the project.
- Students tended to use relatively simple and ubiquitous communication tools (e.g., Skype).
- Teachers were motivated by the professional development opportunities and by the idea that the project would be good for their students.
- Teachers also enjoyed the interactive aspects of participation, including the guest speakers (professional engineers and other STEM professionals)

The above findings, however preliminary, show that the Global STEM Classroom® holds a great deal of promise for a larger-scale rollout. The Global STEM Classroom® is able to tap into students motivations and provide them with meaningful and innovative educational experiences that appear to have exercised significant effects on learning, attitudes, and behavior. There are important aspects of future research that will need to be addressed, however, including: a more complete sample with a full description of the participants, an assessment tool for measuring both fidelity of implementation and extent of exposure, and more work on assessments of learning that are tied to the actual content of the STEM projects.

Introduction

Technological advancement over the last decade has dramatically changed the reality of the professional world of engineers, the way they work and the skills they now require. One of the major changes is that many engineers now work in teams, generally multicultural, either in the United States or internationally, cooperating through technology. Based on the data on international collaboration that were collected in 2006 by SETAT, one in six scientists and engineers in the United States reported working with individuals located in other countries. These scientists and engineers used telephone, e-mail, and Web-based or virtual communication as main means of communicating during their international collaboration. Thus, it is becoming increasingly imperative for today's students— tomorrow's workers— not only to have the opportunity and skills to use various means of communication but to be able to work with people from diverse linguistic and cultural backgrounds.

This growing demand for engineers with global experience requires that K-12 schools expand the number of graduates competent in Science, Technology, Engineering and Math (STEM) and who are interested in pursuing engineering as a career path. However, there is a large disparity between the number of K-12 students who enroll in school each year (the National Center for Education Statistics reported approximately 50.1 million K-12 students enrolled in 2015) and the amount number of students who pursue engineering courses (the National Academy of Engineering reported that from 1990-2009 only about six million K-12 students received any formal engineering education). For the few students who had engineering instruction, the curriculum did not always portray the diversity and excitement of modern technological and collaboratively global nature of 21st Century engineers. This may lower the interest and engagement for students and leave them less prepared if they do

pursue an engineering career path later on (Fralick et al., 2009; Knight & Cunningham, 2004).

There were a few studies, mostly at the level of higher education, which investigated the benefits of study abroad collaborative engineering programs (Streiner et al., 2015). The students who participated in these studies acquired a greater understanding of the current issues that engineers face in a global and social context (Jesiek et al., 2014). However, it may be unrealistic and financially difficult for K-12 students to study abroad and experience the benefits of international learning environments. The new online collaborative technologies that we advance can provide more accessible opportunities for students to gain international experiences by simulating globally dispersed engineering teams, which could potentially lead to increased interest in engineering.

A well-documented body of research now exists on the effectiveness of a form of collaborative learning that uses a network of computers, namely computer-supported collaborative learning (CSCL) (Stahl, Koschmann, & Suthers, 2006). CSCL is a coordinated, synchronous and/or asynchronous activity between two or more learners who collaborate via the computer to solve problems or co-construct knowledge. Learning occurs by means of the articulation and sharing of ideas to be built upon by the collaborating partners (Stahl, Koschmann, & Suthers, 2006). Collaborative learning is an effective instructional approach that can better prepare students as prospective engineers because it fosters working in teams. The skill that is highly valued in the engineering profession. In this study, CSCL with culturally diverse middle/high school students is referred to as Global STEM Classroom®. The Global STEM Classroom® participants complete real-life STEM/engineering (both research and hands-on) projects with an online virtual global student team. In addition, the Global STEM Classroom® involves creating virtual environment of one joint classroom where students from two or more schools in different countries receive instructions from one teacher as if they are in the same classroom (using both synchronous and asynchronous teaching and learning approaches).

Therefore, we believe that the inherent practices of 21st century engineers should inform the way students work and learn about engineering in school. The introduction of this knowledge into, specifically intercultural, collaborative learning environments will allow us to mirror the contemporary internet-based and intercultural workplace of professional engineers in the field. Middle and high school students will not only acquire STEM skills, but also will potentially be inspired to pursue a career in engineering. There is university level research regarding the benefits of international collaborations (in the form of study abroad programs) on the development of beliefs and attitudes towards becoming engineers and scientists (Besterfield-Sacre et al., 2015). However, little is known about how the Global STEM Classroom® (computer supported intercultural collaborative learning) may affect middle/high school students who work on authentic engineering projects and whether this approach can influence students' attitudes and knowledge about engineering and their self-efficacy around novel engineering collaborations. The present study was undertaken to answer the following research question: *What are the attitudinal effects that can be reasonably attributed to participation in the Global STEM Classroom®?* We particularly investigated students' motivation for participation, levels of engagement, the use of various technological tools, problems encountered, attitudinal gains, and interest in continuing to participate in similar projects.

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Theoretical framework

Attitude can be defined as a predisposition towards a stimulus acquired through a person's past experiences (Ajzen, 2001). These past experiences whether they are positive or negative, can determine how an individual will react towards future situations, concepts, people or objects. According to Myers (1993) a combination of emotional, cognitive and behavioral attributes shape the outcome of attitude. According to Social Cognitive Career Theory, attitudes along with values and abilities are three important aspects that determine how someone's career path might develop (Lent & Brown, 2002). There is a positive correlation between a student's familiarity with STEM careers and his/her interest in pursuing STEM professions (Clewell & Campbell, 2002; Robinson & Kenny, 2003). The shortage of students enrolling in engineering courses could be linked to their insufficient knowledge of the actual tasks engineers do at their jobs on a daily basis.

Previous research suggests that interest and positive attitudes towards engineering need to be developed as early as middle school, so that students will desire to enroll in high school courses centered around science and math (Akos et. al., 2007). Without initiating this essential academic path, students are less likely to be academically competent and may lose interest in pursuing college programs and future careers as engineers. Akos and his colleagues (2007) reported that an overwhelming majority of middle/high school students make decisions about their coursework based on preparation for a future college degree or career (Akos et al., 2007). There are more negative attitudes towards science in older students compared to younger ones (Neathery, 1997). Therefore, it is imperative to positively engage students as early as middle school in STEM subjects or they are less likely to enroll in the required high school courses that would be necessary in pursuing future careers in engineering.

How can we facilitate the process of formation of positive attitude towards engineering among middle and high school students? According to Epistemic Frame Theory, developed by Shaffer (2006), the goal of a professional is to create an epistemic frame (values, knowledge, epistemology, identities) through their professional experiences. We believe, of the limited amount of middle/high/high school students who receive engineering instruction, they rarely have access to practical hands-on professional experiences that would form an epistemic frame of engineering. This may explain why some lose interest and quit engineering programs. One approach to this problem is implementation of online collaborative learning environment, so called the Global STEM Classroom® here, that will enable us to mirror the contemporary internet-based and intercultural workplace of professional engineers in the field. By doing so, middle and high school students will work on authentic engineering projects and gain more understanding of the engineering profession; therefore, they might be more likely to form a positive attitude toward engineering.

From a theoretical perspective, socio- constructivist learning theories (Vygotsky, 1978) assert that knowledge emerges from the collaborative problem-solving process in learning communities with information distributed among its members. Collaborative activities such as asking questions and giving explanations are thought to change participants' cognitive structures (King, 1997). The personal and cultural backgrounds of learners are viewed as particularly important because they influence the manner in which the learner attains

knowledge (Wertsch, 1998). Heterogeneous groups and culturally heterogeneous ones, in particular, can benefit from the sharing of different perspectives and different background knowledge (Popov et al., 2014; Popov et al., 2013; Weinberger et al., 2007). From an educational policy perspective, moreover, many schools and universities are using collaborative learning technologies to better prepare students for the world of work. Balakrishnan (2015) has found that the use of CSCL had positive impact on engineering students' learning in terms of their learning achievement and positive attitude towards online collaborations. These findings seem to be consistent with other research on the use of CSCL in engineering education (see for details Rubio et al., 2010; Fuller & Moreno, 2004).

Methods

The study setting

The students from 8th-9th grade (N=112 in total) from US (n=56), Russia (n=28), France (n=14) and UK (n=14) have participated in a Global STEM Classroom® collaborative project on NASA GRACE and climate change in Spring Semester 2013 (January to June). NASA GRACE is a joint international mission and stands for "Gravity Recovery and Climate Experiment".

From one class in one public school in the US (Dennis Yarmouth HS in Massachusetts) and one class from a public school in UK (Finham Park in Coventry, Mid-Land). We formed 7 culturally mixed student groups (in each team two students from US and two student from UK). The collaborative partners met/worked in their groups synchronously two times per week during regular class hours in US -and after school hours in UK. Each team needed to chosen a research topic under the "umbrella" of a major theme "NASA GRACE and Space Exploration". Each team have conducted a collaborative research, developed a Google Drive PPT presentation and collaboratively reported (synchronously via Google Hangout or Skype), the results to the joint UK-US teaching team, other science teachers from both US and UK, other students and parents during the final presentation day. Similar setup was done with two more classes from Moscow, Russia (Lyceum "Vtoraya shkola" and Gymnasium #53) and one more class from France (Ballan-Mire) with the US students as their collaborative partners.

During the Global STEM Classroom®, the students engaged in hands-on collaborative activities devoted to NASA GRACE data collection and data visualization, data processing, plotting and interpretation; ice sheet/water content changes for specific regions: Antarctica, Greenland, CA valley, 16 basins of Greenland (each team have chosen a different global region). Guidance for teachers was provided by one of the NASA GRACE mission specialists. The students collectively studied the materials provided by NASA GRACE mission http://www.nasa.gov/mission_pages/Grace/#.VtB7wOaauNo and had a DVD disk provided by the American Museum of Natural History http://www.amnh.org/explore/curriculum-collections/grace. There were four staff members from each school (US, UK, France, Russia/Russia) 20 staff member (one lead-

science teacher, one assistant science teacher, IT Director and one IT technician or, one Foreign Language and one IT technician.

Sample, data collection and analysis

The sampling frame for the 2013 Global STEM Classroom® student survey was determined in consultation with the GTEC leadership. Participating students were provided the link to the SurveyMonkey site and completed the survey online. The final respondent sample for the survey included 30 students (28 from the US and 2 from Russia) from the classrooms of three teachers). Students ranged in ages from 13 to 18, with the average age of about 15, and about 2/3 of the respondents being female. The respondent composition by class and gender is presented in the following table:

Teacher	Boy	Girl	Total
2	1	5	6
3	7	11	18
4	2	4	6
Total	10	20	30

The survey instrument itself was created through the collaboration of the project with the external evaluator (DSRA) and explored the participant perceptions of program components and the resultant attitudinal effects of participation (the survey can be found here https://www.surveymonkey.com/r/BV8332G). The Cronbach Alpha reliability value for the survey was calculated at a very high 0.930, providing some indication that the survey was consistent in its measurements. No construct validity analysis was undertaken as the sample size was too small.

The rather long survey included 120 items, including 10 open responses. The six central domains of the survey included motivation for participation (e.g., 'I am interested in collaboration with students from other countries'), levels of engagement ('I am interested in science and engineering components of the program'), the use of various technological tools, problems encountered, attitudinal gains, and interest in continuing to participate in similar projects (e.g., 'I believe that this program is highly beneficial for me in general'). The research model was a within-group, change-over-time model and data collection relied largely upon pre-post survey findings to determine whether the Global STEM Classroom® was effective at meeting its declared objectives. Subsequent analyses and visualizations were done either in SPSS or R, with the bulk of the statistics being non-parametric. The overarching research question for the student survey included:

What are the attitudinal effects of participation the Global STEM Classroom® in terms of students' motivation for participation, levels of engagement, and interest in continuing to participate in similar projects?

Results

Findings from the survey covered a wide range of points, and these will be summarized in the following bullet points:

- Students chose to participate because they were motivated by the content, the possibility of collaborating internationally, or because they thought it would be good for their academic careers.
- Students most enjoyed the interactive aspects of the project.
- Students tended to use relatively simple and ubiquitous communication tools (e.g., Skype).
- Teachers were motivated by the professional development opportunities and by the idea that the project would be good for their students.
- Teachers also enjoyed the interactive aspects of participation, including the guest speakers

The following series of density plots show examples of the distributions some of the reported pre-post gains in the target constructs. The constraints of space limit what can be presented, though the reader will no doubt glean some insights into the relative effectiveness of the Global STEM Classroom®.

The first set of density plots show the statistically significant ($p<.05$, Wilcoxon) shift in the students' attitudes toward the study of engineering in this context.

Density Plot of Student Gains
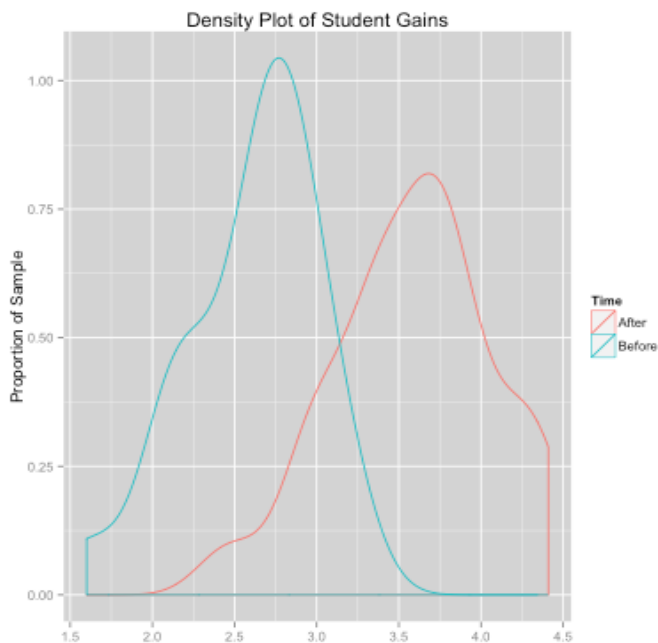
The following density plots show the statistically significant ($p<.05$, Wilcoxon) shift in teachers' engineering talk.

Teacher Increase in Engineering Talk
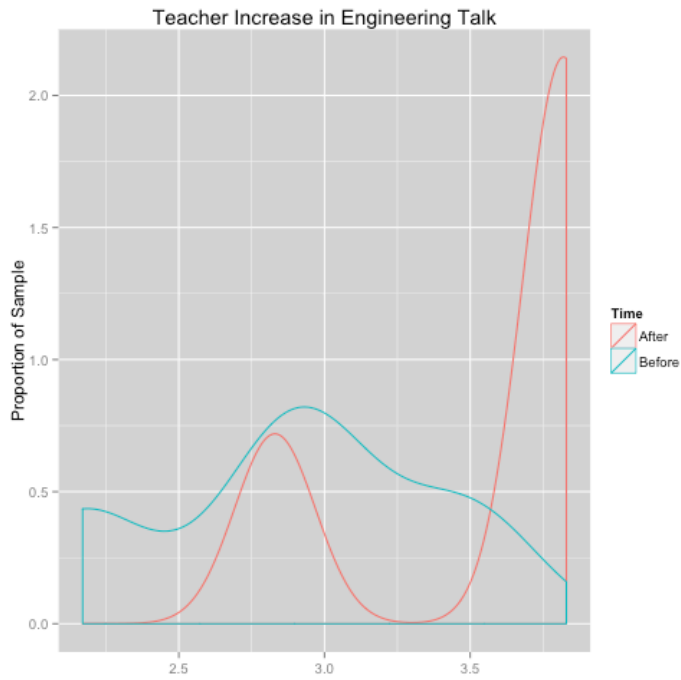
A final pair of density plots shows the statistically significant pre-post increase ($p<.05$, Wilcoxon) in the teachers' reported levels of self-efficacy in teaching engineering.

Teacher Increase in Self_Efficacy
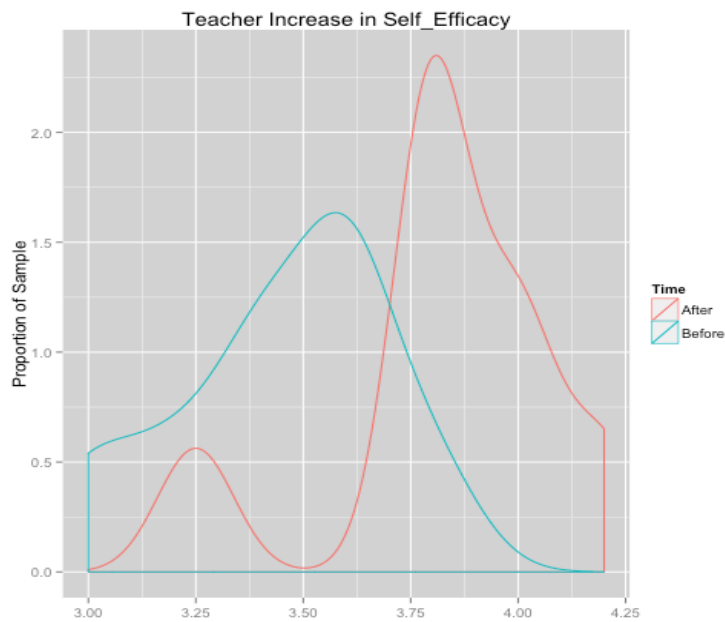
Conclusion

The above findings, however preliminary, show that the Global STEM Classroom® holds a great deal of promise for a larger-scale rollout. Thus study was able to tap into participant motivations and provide participants with meaningful and innovative educational experiences that appear to have exercised significant effects on learning, attitudes, and behavior. There are important aspects of future research that will need to be addressed, however, including:

- A more complete sample with a full description of the participants
- An assessment tool for measuring both fidelity of implementation and extent of exposure
- More work on assessments of learning that are tied to the actual content of the project
- Additional work on the validation of the project research instruments, perhaps expanding these with a mode developed track of qualitative inquiry.

Previous research findings indicate that if engineering students are properly prepared for working in an international environment prior to the experience, which includes being clear about their own expectations and how they are connected to the experience, they will be able to optimize their engineering learning goals and become more globally adept (Ragusa et al., 2014). Simply placing students from different cultures together in a group does not appear to lead to successful learning experiences (Lin & Kinzer, 2003). It is necessary, rather, to emphasize the importance of preparation for the intercultural group projects and reflection activities after their international collaborations, in order to recognize and acknowledge the impact of these experiences on their cognitive, attitudinal, social and behavioral development. Future research studies may investigate a number of interventions that could help students reap the benefits such learning experiences. These could include: reflection activities through discussions for increased meaning, and guided facilitation of collaborative activities (e.g., through collaboration scripts (Popov et al. 2013) and teachers' active leadership roles in cultivating students' attitudes, knowledge, and skills.

Overall, based on these preliminary findings Global STEM Classroom® hold promise for the STEM education. The Global STEM Classroom® model, considered as a kind of pedagogical "container space," could well support any number of other content areas, or even trans-disciplinary inquiry. Building on the participants' interest in international contacts and technology, the Global STEM Classroom® is in an excellent position to help students extend their social and cognitive networks, help them to experience the building of social capital, and assist them in the derivation of considerable learning and attitudinal benefits in the process.

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