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EDITORIAL

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In this issue of J-STEM, we have five articles focusing on diverse issues in STEM education. Best, Best and Dickter (2019) explore whether pedagogical and curricular features of a STEM curriculum called, STEMtrix program they have designed increase minority students', specifically African American students' self-efficacy and self-concept to pursue a STEM career. Their study has specific implications for designing out of school STEM experiences that are meaningful and built based on pedagogically sound principles.

Newton and colleagues explore students' experiences with scientific practices more specifically their experiences with experimental design, data representation/visualization and data-based decision making in middle schools in the Evaluation Approach: Practice-Focused Middle School Science Modules article. The article explores the impact of these learning modules on students from four middle schools. They make a valuable contribution to the field as there is a heightened interest in integration of data and data-related practices in school science curriculum. The modules they developed, implemented and evaluated can serve as examples for those aiming to design similar modules and the evaluation methods they have used can serve as a resource for those interested in curriculum design and impact studies.

Demir, Gul and Czerniak (2019) focus on an important issue, the recruitment of STEM teachers. They build on their three-year program focusing on the recruitment of STEM teachers and the relevant literature to recommend recruitment strategies for increasing the pool of potential STEM teachers starting from high school.

Fridberg and Redfors (2019) introduce an interesting concept, specifically the didactic game taking place between the children and their teachers during inquiry-based STEM activities using the Joint Action Theory of Didactics. They explore if utilization of digital tools makes a difference in how the teachers implements the inquiry-based activities. Their findings make valuable contributions to the ways in which teachers enact inquiry-based activities and highlight the role of teacher in facilitating student learning in early grades.

Griffith (2019) from the University of West Indies explores the extent to which the end of secondary school examinations reflects the ideals of recent curriculum efforts in STEM education in the Caribbean in the Growth rate in CXC STEM subject entries, Implications for meeting the developmental needs of the Caribbean. Based on the findings of his analysis Griffith problematizes fidelity of reform efforts and makes policy recommendation for effective implementation of reform implementation.

Collectively, the articles in this issue of J-STEM make unique contributions to the STEM education literature ranging from early childhood education to teacher recruitment.

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RESEARCH REPORT

STEAM Programming as a Pathway to Foster Positive Academic Self-Efficacy and Positive Self-Concept

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Abstract: *Multicultural individuals are underrepresented in the fields of science, technology, engineering, and mathematics (STEM). Therefore, the current study is focused on exploring STEAMtrix, a STEM out-of-school time (OST) education program that incorporates the arts (STEAM) for kindergarten through 12th grade (K-12) students. The study explores whether STEAMtrix could lead to interest and awareness of careers within the STEM pipeline. Specifically, the study examined whether the pedagogical and curricular features of STEAMtrix could improve underrepresented students' formation of positive STEM-specific self-efficacy and self-concept. Thirty-eight students from African American and biracial, African American and Caucasian, backgrounds at a medium-sized community center participated in STEAMtrix, an eight-session STEAM OST curriculum. Explicit measures of STEM self-efficacy and both explicit and implicit measures of self-concept were collected before and after programming. Results demonstrated that the pedagogical and curricular features of STEAMtrix increased STEM self-efficacy in some domains and improved implicit self-concept. This study offers insight into how community organizations and school systems can promote early access, positive self-efficacy, and positive self-concept in relation to STEM educational experiences during OST.*

Keywords: *Multicultural, science, technology, engineering, and mathematics (STEM), out-of-school time (OST), science, technology, engineering, arts, and mathematics (STEAM), kindergarten through 12th grade (K-12), self-efficacy, self-concept*

Introduction

The professional opportunities in science, technology, engineering, and mathematics (STEM) fields are projected to increase at higher rates than those of non-STEM fields (Best, 2016; Fayer, Lacey, & Watson, 2017; Langdon, Mckittrick, Beede, Khan, & Doms, 2011). However, multicultural individuals are less likely to continue in pursuit of a STEM degree than their counterparts (Bianchini, 2013; Maton, Sto Domingo, Stolle-Mcallister, Zimmerman, & Iii, n.d.; Zatz, Gates, Santiago, & Johnson, 2017). Multicultural individuals are those from racial and ethnic groups that have been shown by the National Science Foundation (NSF) to be underrepresented in health-related sciences on a national basis (Lehming, Gawalt, Cohen, & Bell, 2013; National Science Foundation & National Center for Science and Engineering Statistics, 2019). The racial and ethnic groups included within the NSF definition are Blacks or African Americans, Hispanics or Latinos, American Indians or

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Alaska Natives, and Native Hawaiians and other Pacific Islanders. The term multicultural is rooted in the belief that different cultural or racial groups have equal rights and opportunities in a society, including that to education (Byars-Winston, 2014; Nieto & Bode, 2012). Multicultural individuals enter the STEM pipeline, but some do not ultimately remain in STEM, which creates gaps that result in the disproportionate number who obtain STEM careers (Griffith, 2010; Huang, Taddese, & Walter, 2000; Malcom & Feder, 2016; Maton et al., n.d.; Riegle-Crumb, King, & Irizarry, 2019).

Eighty-four percent of working professionals in STEM fields are Caucasian or Asian males (Jackson, Charleston, Lewis, Gilbert, & Parrish, 2017; Lehming et al., 2013), and almost 70% of full time scientist and engineers are Caucasian (National Science Foundation & National Center for Science and Engineering Statistics, 2019). The aforementioned statics are a result of numerous factors including lack of early access, poorer educational systems, lack of social capital and status, and lower self-esteem (Ashby, 2006; Funk & Parker, 2018). Collective findings suggest that there is a pipeline issue with retaining racially diverse STEM talent, as non-cognitive, social-psychological, and demographic factors affect these students' selection and persistence in STEM majors (Berube, Eubanks-Turner, Mosteig & Zachariah, 2017). In order to address the shortage of U.S. STEM workers, racially diverse talent must be recruited from the American school system and retained in the STEM pipeline (Best, 2016; Fayer et al., 2017; Langdon et al., 2011). There are multiple barriers that lead to this shortage, especially in under-served communities such as resource availability, hiring and retention of quality teachers, and educational enrichment accessibility (Adetunji & Levine, 2015; Bargagliotti, Herreiner, & Phillips, 2018). However, it is important to also reimagine kindergarten through 12th grade (K-12) STEM education in ways that are relevant to underrepresented students.

The STEAM Movement

Dr. Judith A. Ramaley, the former director of the NSF Education and Human Resources Division, is credited with defining the science, technology, engineering, and mathematics curriculum as the acronym STEM (Carmichael, 2017). The STEM curriculum has garnered support from various professional and educational institutes, but there still remains little consensus on how the curriculum should be effectively taught in schools (Eleftheria, Sotiriou, & Doran Ellinogermaniki Agogi, 2016; Reinholz, 2018; Ting, 2016). The lack of consensus in part, has paved the way for the development of out-of-school time (OST) programs as avenues to supplement what is taught in the traditional academic setting. Since the cultivation of the STEM movement, a number of STEM-based extensions have galvanized. One such extension is STEAM, which advocates for the necessity of the arts within the STEM curriculum (Bequette & Bequette, 2012; Daugherty, 2013; Madden et al., 2013). Georgette Yakman is the founding researcher and creator of STEAM education (Yakman, 2015). In 2006, she developed the framework and began its implementation in 2007 as a middle and high school engineering and technology teacher (Yakman, 2015).

The integration of art and design in the STEM education conversation has the potential to make STEM more appealing to a wider demographic, including multicultural students, and thus increase overall engagement with STEM fields (Bequette & Bequette, 2012; Daugherty, 2013; Jolly, 2014; Land, 2013). Many support STEAM, but concerns remain on whether the arts belong and if arts are included, then why not the other humanities (Jolly, 2014; Land, 2013). The STEM to STEAM movement is in part a reflection of collaborations and jointly funded projects through the NSF and National Endowment for the Arts, two predominant federal agencies responsible for the promotion of STEM and the arts respectively (Barrett, Anttila, Ruthmann, Haseman, & Ghanbari, 2015; Berube et al., 2017; Carroll, 2015; Kuenzi, 2008).

STEAM as a Pathway to Foster Innovation

The increase of available funding has resulted in development of STEAM programs at the national, state, and local levels (Bush et al., 2016; Daugherty, 2013; Dekhtyar & Schaffner, 2018; Miel, Portsmore, Maltese & Paul, 2018). Through a lens of innovation, STEAM-based curricula integrate scientific training with creative development (Madden et al., 2013). The novelty behind the STEAM movement is the shift in perceptions of STEM topics from unapproachable to include creative and real opportunities for expression (Guyotte, Sochacka, Costantino, Walther, & Kellam, 2014; Miller

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& Knezek, 2013). Additionally, the arts are a creative learning tool that can serve as a gateway to STEM for multicultural students (Jolly, 2014). Art activities increase motivation, offer more diverse learning opportunities, and provide greater access, all of which increase the probability of STEM success (Jolly, 2014). However, more research needs to examine the effect that STEAM programming has on increasing academic, and even more specifically STEM, success. Self-efficacy and self-concept are two of the most significant predictors of educational success such as performance and effort (Marsh & Martin, 2011; Pajares, 1996; Valentine, DuBois & Cooper, 2004). Therefore, it is important to examine these two constructs when evaluating the effectiveness of a STEAM program.

Self-Efficacy

To ensure that multicultural individuals are adequately represented in STEM careers, their academic self-efficacy must be encouraged and supported as early as the K-12 level (Marra, Rodgers, Shen, & Bogue, 2009; McClary, Zeiber, Sullivan, & Stochaj, 2018; Rinn, Miner, & Taylor, 2013). Self-efficacy refers to situation-specific self-confidence before STEM subject with such as in this context (Bandura, Barbaranelli, Caprara, & Pastorelli, 1996). Self-belief influences task choice, level of effort, persistence, and subsequent performance (Bandura, 1997; Hajloo, 2014). Self-efficacy is one of the strongest performance domain factors especially in academic settings (Hajloo, 2014; Pajares, 1996). Underdeveloped academic and STEM-specific self-efficacy may be at least partially the result of racial stereotypes targeted towards multicultural students (Reinholz, 2018; Soe & Yakura, 2008). In order to foster positive academic and STEM-specific self-efficacy, targeted opportunities for early STEM education should ensure that all students are granted opportunities to take courses in school and participate in quality STEM OST programs.

Self-Concept

In addition, the development of positive self-concept can foster recruitment and retention of multicultural individuals in the choice of pursuing STEM careers (Betz & Hackett, 1986; Carpi, Ronan, Falconer, & Lents, 2017; Dabney et al., 2012). Self-concept is represented as judgements of global self-constructed beliefs that reflects one's view of accomplishments, capabilities, values, body, others' responses, events, occasions, and possessions (Bandura, 1997; Hajloo, 2014; Tesser, 2000). In educational systems across the world, improving general feelings of self-concept has been identified as an important goal (Dévai, Katona-Sallay, Pekrun, & Kalliopuska, 1990; Gwirayi & Shumba, 2007; Klapp, 2018; Sui-Chu Ho, 2003; Yeung, Craven, & Ali, 2013). More specifically, individuals and organizations have acknowledged that positive self-concept is associated with desirable educational outcomes, including academic performance (Marsh & Martin, 2011) and motivation and effort (Thomas & Gadbois, 2007). Although assessing self-concept using self-report methods is important, previous work examining participation and interest in STEM fields has demonstrated that situational cues affect self-concept. For example, exposing women to ingroup role models in STEM settings increases their implicit but not explicit self-concept (Stout, Dasgupta, Hunsinger, & McManus, 2011), suggesting that self-concept is more reliably assessed with implicit rather than explicit measures (Markus & Kunda, 1986). Since there are established measures for explicit and implicit self-concept that can predict different behaviors and intentions (Greenwald et al., 2002), it is important to use both to holistically assess self-concept.

The Development of STEAMtrix

To address the underrepresentation of multicultural individuals in the STEM pipeline, we developed a novel program that uses the STEAM movement to encourage the development of positive self-efficacy and self-concept in STEM fields. STEAMtrix is a STEM OST education program that incorporates the arts within a science-based curriculum. The STEAM-based programming seeks to encourage student proficiency in both convergent thinking, typically acquired in STEM lessons and divergent thinking, typically acquired in the arts (Guilford, 1956; Land, 2013). These contrasting approaches are cultivated during project-based learning, which is designed to develop students' interest and awareness of careers within the STEM pipeline. The mission of STEAMtrix is to provide K-12 students with innovative opportunities to participate in STEAM activities outside of the traditional academic setting. Although STEAMtrix serves all students, students from underrepresented populations in STEM fields, including multicultural individuals and females, are the targeted populations. The pedagogical and curricular features of STEAMtrix provide targeted opportunities that promote early access, positive STEM self-efficacy, and positive self-concept. In doing so, the STEAMtrix pedagogical and curricular features respond to the unique needs of all students, specifically multicultural individuals.

The Pedagogical Features of STEAMtrix

The overarching pedagogical features of STEAMtrix are the cultural relevancy of STEAMtrix and the curriculum, the integrative approach by which instructors teach the curriculum, and the inclusive environment that promotes a sense of belonging. A national culturally relevant need is for a more racial and gender diverse STEM pipeline. As a culturally relevant response, STEAMtrix seeks to expose underrepresented students to hands-on STEM activities and engagement with STEM fields. Further, the STEAMtrix curriculum is centered around a topic that many students have familiarity. Throughout the lessons, students are provided with the resources to build upon STEAM concepts. This promotes the development of more positive self-efficacy and self-concept as students are made aware of STEM career possibilities. Therefore, exposure, experience and engagement, some of the unique needs of multicultural students (Byars-Winston, 2014; Nieto & Bode, 2012), are met as a conduit toward the selection of future STEM careers.

Currently, school-based curricula introduces STEM in a siloed approach, wherein each content area is taught mutually exclusive from the next (Eleftheria et al., 2016). In contrast, STEAMtrix integrates STEAM through language, hands-on activities, and presentation opportunities. Therefore, within the STEAMtrix framework, learning is incubated and explored at each student's level, allowing multiple age groups to engage with integrated STEAM fields. In doing so, concepts particular to each content area-based session are reinforced throughout the duration of the curriculum. For example, the presentation session built into the curriculum integrates and highlights the cumulative work that was done throughout the program. Each content areas session, leading to the final presentations, highlights a multicultural individual from popular culture who has received a higher learning degree in the content field related to the session. The virtual exposure to multicultural individuals from STEM career backgrounds paired with those who instruct in person as guest speakers, presenters, and/or volunteers further enhances the student's self-efficacy and self-concept, as they see someone who resembles them as a STEM professional. The connections students make with these individuals contributes to their empowerment and development of more positive feelings towards STEM fields as they now have models of success in STEM. Most academic settings seek to employ a pedagogy of belonging to meet the student's psychological need to feel as if they are accepted and belong (Beck & Malley, 1998). However, STEAMtrix has taken the sense of belonging one step further as students are made aware that they belonged in STEAMtrix, and in STEM careers. For some students, their STEAMtrix experience was the first time they had been exposed to a person in the STEM field that resembled them.

The Curricular Features of STEAMtrix

The STEAMtrix curriculum can be adapted for multiple age groups. The STEAM units are taught in the same order with the same expectation for the students to achieve benchmarks of skill (behavior, analytical, communication, and teamwork skills), knowledge, and dispositional goals. The STEAMtrix goals are based in the performance indicators (quantitative and qualitative) and objectives (program, cognitive, affective, behavioral, developmental, instructional objectives). The differences of the curricular features are based in the expectation of how the students present their outcomes. For example, more junior students can draw as an alternative to writing in their notebooks throughout the curriculum. The first session, of STEAMtrix the students were introduced to the program, team building, and how to operate the program measures. Concurrent sessions two through six are content based where STEAM is integrated. In these sessions, students are presented with project-based activities that provide spaces for their empowerment of themselves and the communities they represent. Session seven involves the preparation and presentation as students demonstrate knowledge of various completed projects to peers, family, and community partners.

During the final session, the students complete the post programming measures and receive a certificate of completion.

This paper will describe how STEAMtrix's pedagogical and curricular features aim to foster the formation of positive STEM self-efficacy and self-concept that sustains multicultural students' interest and awareness of careers within the STEM pipeline. In addition, this paper also assesses the effectiveness of the program in achieving these goals. Previous research suggests that effective STEM programs should use a project-based, culturally responsive, pedagogy-centered STEM curriculum to help students develop strong STEM self-efficacy (Davis & Hardin, 2013). According to the National Research Council, the following goals must be met in an effective STEM OST program:

1. engage young people intellectually, academically, socially and emotionally
2. respond to young people's interest, experiences and cultural practices
3. connect STEM learning in out-of-school, home, and other settings (Caplan, 2018, p.2).

STEAMtrix was designed to accomplish these goals by incorporating the visual and performing arts within the STEM paradigm to encourage student interest and awareness of careers within the STEM pipeline (Segarra, Natalizio, Falkenberg, Pulford, & Holmes, 2018). Across the country some schools at the K-12 grade level have integrated art into STEM curricula with increased reported student success (Krigman, 2014; Williams, 2014). STEM and arts integration ideas have been supported by lawmakers, who launched a STEAM Caucus in the U.S. House of Representatives that advocates for arts education and integration being essential in producing the future workforce (Krigman, 2014). The integration of arts into the STEM curriculum is particularly impactful for multicultural students, who are often labeled as "at risk" (Barone, Bresler, & Betts, 2006; Catterall, Dumais, & Hampden-Thompson, 2012). Arts involvement reinforces multicultural students' achievement in STEM, which could eventually narrow the gap in the STEM workforce (Catterall et al., 2012; Rabalais, 2014; Sousa & Pilecki, 2013; Van Der Veen, 2012). In addition, increased self-efficacy and positive attitudes, particularly among low income students, has also been linked to increases in arts instruction, which further supports arts' potential role in encouraging STEM interest (Barone et al., 2006). Furthermore, empirical data and theoretic foundations have connected arts to cognition, student performance, enhanced creativity, deeper learning, and cultural empathy (Rabalais, 2014). A study using the National Assessment of Educational Progress, similar to prior research studies, identified a relationship between increased exposure to the arts and performance in STEM subjects, especially for multicultural students (Rabalais, 2014). In order for traditional STEM programs to be effective it is argued that positive, engaging or interactive environmental factors are needed, among additional factors, to influence student interest (Byars-Winston, 2014). Therefore, arts may be the missing component in the charge of increasing the number of multicultural individuals recruited and retained in the STEM workforce (Rabalais, 2014).

The overall goal of STEAMtrix is for underrepresented students to envision themselves as successful in a variety of STEM careers. The pedagogical and curricular features of STEAMtrix that feature the culturally relevant curriculum used in this case study provide individuals with the opportunity to explore STEAM fields over the course of an eight-session program. The goal of the current study was to assess the effectiveness of the pedagogical and curricular features of STEAMtrix in enhancing self-efficacy and self-concept. It was hypothesized that the program would lead to increased positive STEM self-efficacy as measured by an individual's interest and awareness of careers in the STEM pipeline. Both explicit and implicit self-concept were measured. Importantly, research has demonstrated interventions targeted at individuals from social groups underrepresented in STEM fields improve implicit but not explicit self-concept (Stout et al., 2011). Thus, it was expected that the current program would only improve implicit self-concept.

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Method

Participants

Thirty-eight African-American and two biracial, African-American and Caucasian, K-12 students participated in eight sessions of STEAMtrix at the Salvation Army Boys & Girls Club in Richmond, Virginia's East End. These multicultural students ranged in age six to 13. There was a gender imbalance with 27 girls and 11 boys. The sessions were held one day a week, over the course of eight weeks during the Boys & Girls Club Summer Program, which is subdivided into four, two-week sessions (June 17th – August 16th). The then Program Director from STEAMtrix collaborated with an Associate Professor in the Department of Psychology at William & Mary, a mid-sized public university near the area to create materials to assess the efficacy of the program. All procedures were approved by the university's Protection of Human Subjects Committee and the Program Director of the Boys & Girls Club. Students were given the opportunity to self-selectively take part in the study. Consent forms were completed by their guardians. Before pre-program measures were collected at the Boy & Girls Club, students completed informed assent forms that were read aloud by the researcher prior to the study. Students were eligible for the study if they turned in a completed (1) STEAMtrix application, (2) informed consent form, and (3) informed assent form. Following the reading of the assent form, students were invited to ask questions about the procedure. Students were told that they had the right to not participate in the study, at their choosing. Further, they would not be penalized for refusal to answer any of the questions they did not wish. The privacy and confidentiality of all students will always be maintained, through the use of encrypting the data with codes that protect the identity of each participant. The researchers decided to make student comfort a priority while providing information through use of a computerized survey system. The risk in this study was considered to be minimal, since the probability and magnitude of harm or discomfort anticipated in the research was not greater than that experienced ordinarily in daily life (Binik & Weijer, 2014).

Materials

Self-Efficacy

To assess explicit STEM self-efficacy, the students were asked to complete a self-report measure run through Survey Monkey, an online survey software that provides customizable surveys. The questions from the survey were extrapolated from previously validated surveys (Erkut & Marx, 2005; Faber, Walton, Booth, Parker, & Corn, 2013; U.S. Bureau of Labor Statistics, 2009; Unfried, Faber, Stanhope, & Wiebe, 2015). As a measure of STEM-specific self-efficacy the students indicated all related subjects they liked and could obtain as a job.

Self-Concept

Explicit. To assess explicit self-concept, the students were asked how much they thought the following sentences described them on a five-point Likert scale, (1) very probably not to (5) definitely (Mcleod, 2008). The sentences were: "If I work hard I can accomplish my goals…", "I am just as smart as other kids my age…", and "I can go to college…".

Implicit. The Implicit Association Test (IAT; Greenwald, Mcghee, & Schwartz, 1998) assesses the basic evaluative associations people hold toward attitude objects without relying on self-report. The IAT in the current study is used as an implicit measure of a students' implicit self-concept (Greenwald et al., 1998; Nosek, Banaji, & Greenwald, 2002). The Self-Concept IAT (Custom Items) assesses the degree to which respondents implicitly associate attributes (e.g., pleasant, unpleasant) with personal terms (e.g., self, others) gathered from students (e.g., name, hometown, etc.) to use as stimuli representing the "me" and "other" target categories (Greenwald et al., 2002; Greenwald, Nosek, & Banaji, 2000). This paradigm presents students with the opportunity to add in personal information to be used within the paradigm. Students are asked to categorize attributes belonging to Pleasant vs. Unpleasant and items belonging to categories Self vs. Others into predetermined categories via keystroke presses. The basic task is to press a left key (E) if an item (e.g. "pleasure") belongs to the category presented on the left (e.g. "Pleasant") and to press the right key (I) if the word

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(e.g. "gloom") belongs to the category ("Unpleasant") presented on the right. For practice, students sort items into the categories "Pleasant vs. Unpleasant" and the categories "Self vs. Other". For the test, students are asked to sort items into the paired/combined categories (e.g. "Self OR Pleasant" on the left vs. "Other OR Unpleasant" on the right). Pairings are reversed for a second test (e.g. "Other OR Pleasant" on the left vs. "Self OR Unpleasant" on the right). Order is counterbalanced by group number. After the students completed the Self-Concept IAT (Custom Items), they were automatically taken to the previously described self-report survey

Procedure

All parts of the study were run through Inquisit by Millisecond Software (Greenwald, Nosek, & Banaji, 2003), which is used by behavioral scientists to create and administer numerous cognitive and social reaction-time based measures. In order to obtain data on the effectiveness of STEAMtrix, measures were assessed at two time points: Time 1, before programming sessions and Time 2, after programming sessions. At each time point, students completed the measures seated at a private computer station in small groups of two to four. Students were told that they would be playing a game, of which the purpose was to examine their responses to words. First, students completed the Self-Concept IAT (Custom Items) behavioral task that took approximately 5-10 minutes (Nosek et al., 2002). Second, students completed an additional behavioral task that took approximately 5-10 minutes; data from this task are not included in the current paper. Third, students completed the STEM Computer Task self-report survey that took approximately 15 minutes. During the STEM Computer Task students also provided information about their race, age, and gender. When complete, students were thanked, given a snack, and dismissed.

Results

The Time 1 measure included 32 responses. The Time 2 measure included 35 responses. Only students who completed both measures were included in the analysis below ($n = 29$). The results were analyzed using Statistical Package for the Social Sciences (SPSS) software. Figures one through four were made using GraphPad Prism 8. Figure five was created with BioRender.com.

STEM Self-Efficacy

In order to examine changes in explicit measures from Time 1 to Time 2, a series of 2-tailed paired Student's t-tests were conducted. As demonstrated in Figure 1, results with statistical significance revealed that the ability to like Technology (Pair 2) was greater at Time 2 ($M = 0.52$, $SD = 0.51$) than at Time 1 ($M = 0.31$, $SD = 0.47$), $t(28) = -2.27$, $p = .031$. The results with statistical significance revealed that the ability to obtain a job in Science (Pair 6) was greater at Time 2 ($M = 0.48$, $SD = 0.51$) than at Time 1 ($M = 0.22$, $SD = 0.42$), $t(28) = -2.56$, $p = .017$. The results with marginal significance revealed that the ability to obtain a job in Technology (Pair 7) was greater at Time 2 ($M = 0.48$, $SD = 0.51$) than at Time 1 ($M = 0.30$, $SD = 0.47$), $t(28) =-1.73$, $p = .096$. The results with marginal significance revealed that the ability to obtain a job in Engineering (Pair 8) was greater at Time 2 ($M = 0.41$, $SD = 0.50$) than at Time 1 ($M = 0.22$, $SD = 0.42$), $t(28) = -1.72$, $p = .096$. No other tests were statically or marginally significant.

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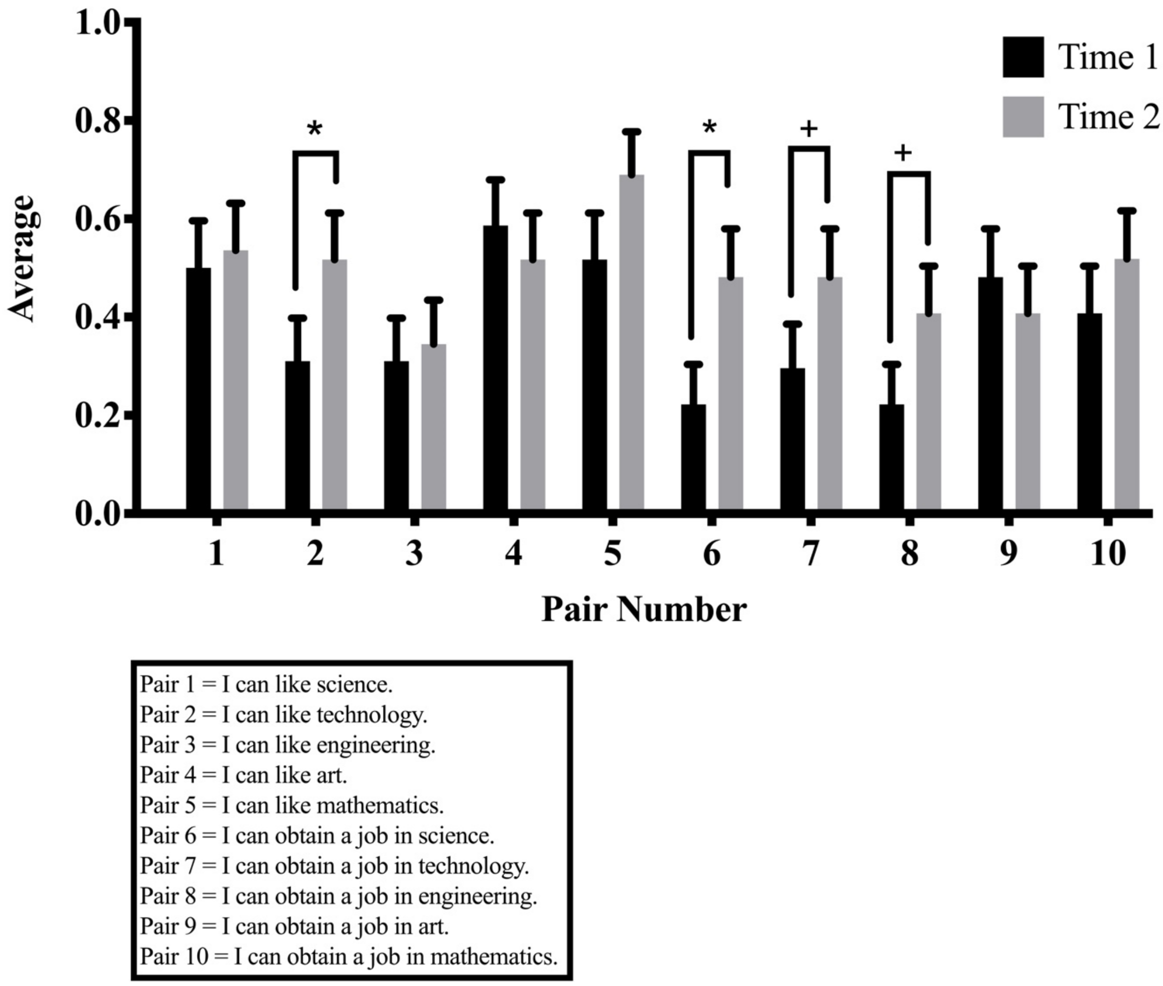

Figure 1. Explicit Measures Demonstrate Improved STEM-Specific Self-Efficacy. Interleaved bar graphs show mean value with standard error mean for the cohort of STEAMtrix students (n = 27-29) determined using 2-tailed paired Student's t-test, which found significant (*), marginal (+), or no effects. Pair numbers correspond to questions on the self-report explicit measure of STEM self-efficacy.

Self-Concept

Explicit. As demonstrated in Figure 2, when asked if students felt they could accomplish their goals if they worked hard (Pair 1), there were no differences between scores at Time 1 (M = 1.63, SD = 1.01) and Time 2 (M = 1.56, SD = 0.85). There was no difference between Time 1 (M = 2.07, SD = 1.01) and Time 2 (M = 1.81, SD = 0.79) on students' feelings of being just as smart as other kids their age (Pair 2). There was no difference between Time 1 (M = 1.44, SD = 0.92) and Time 2 (M = 1.24, SD = 0.52) on students' feelings that they can go to college (Pair 3).

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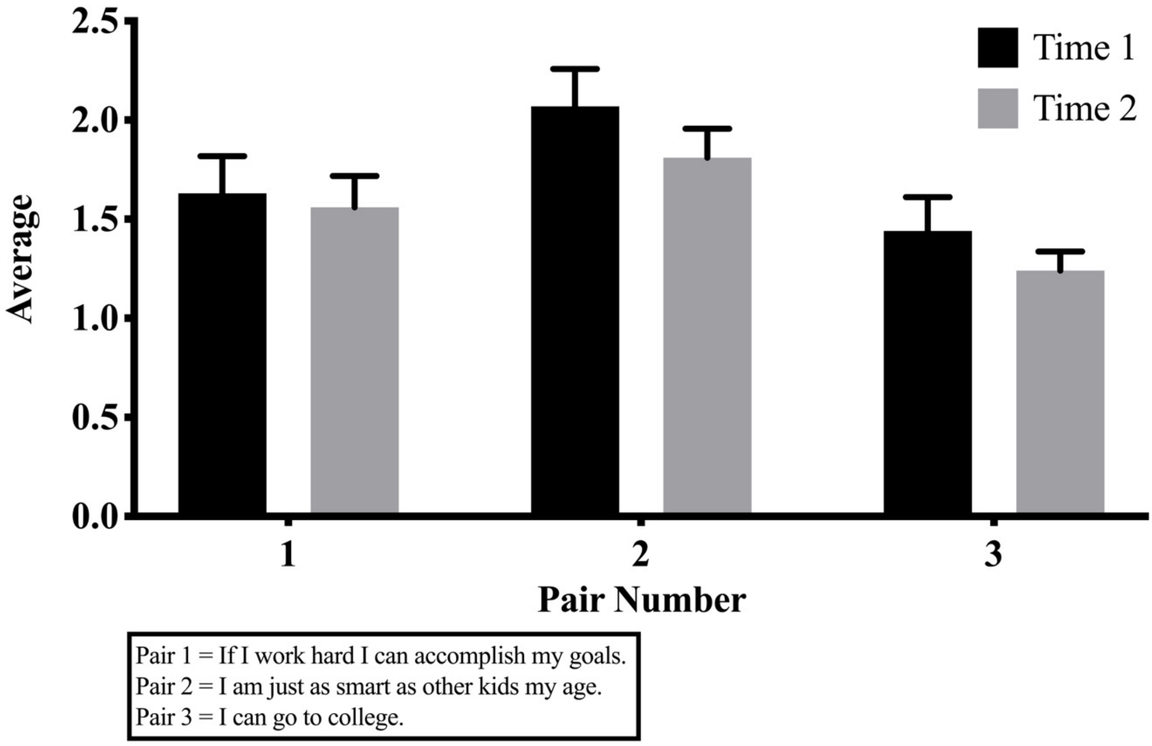

Figure 2. Explicit Measures Demonstrate No Change in Self-Concept. Interleaved bar graphs show mean value with standard error mean for the cohort of STEAMtrix students (n = 29) determined using 2-tailed paired Student's t-test, which found no effects. Pair numbers correspond to questions on the self-report explicit measure of STEM self-concept.

Implicit. The strength of an association between concepts was measured by the standardized mean difference score of the 'hypothesis-inconsistent' pairings and 'hypothesis-consistent' pairings, referred to as a difference or d-score (Greenwald et al., 2003). In general, the more positive the d-score the stronger the association between the 'hypothesis-consistent' pairings, like 'Self-Pleasant' and 'Other-Unpleasant' than for the opposite pairings. Negative d-scores suggest a stronger association between the 'hypothesis-inconsistent' pairings like 'Other-Pleasant' and 'Self-Unpleasant'. The IAT was scored using Greenwald et al.'s (2003) revised method. Accordingly, two students with greater than 10% of latencies less than 300 milliseconds, on the IAT were eliminated from analysis, because their short reaction times indicated that they were likely not paying attention to the instructions and were just hitting the keys as fast as possible without trying to be accurate. The difference scores were calculated as the difference between Time 2 and Time 1. As demonstrated in Figure 3, for the Self-Concept IAT (Custom Items), the mean calculated d score was 0.24 (SD = 0.30) at Time 1 and 0.02 (SD = 0.47) at Time 2. These means were different from zero at Time 1, $t(24) = 2.63$, $p = .041$, and marginally different from zero at Time 2, $t(22) = 2.03$, $p = .056$, indicating a negative implicit association with self-concept. These scores improved, however from Time 1 to Time 2, with the means showing a marginally significant difference, $t(24) = 1.96$, $p = 0.061$, indicating improved implicit association with self-concept.

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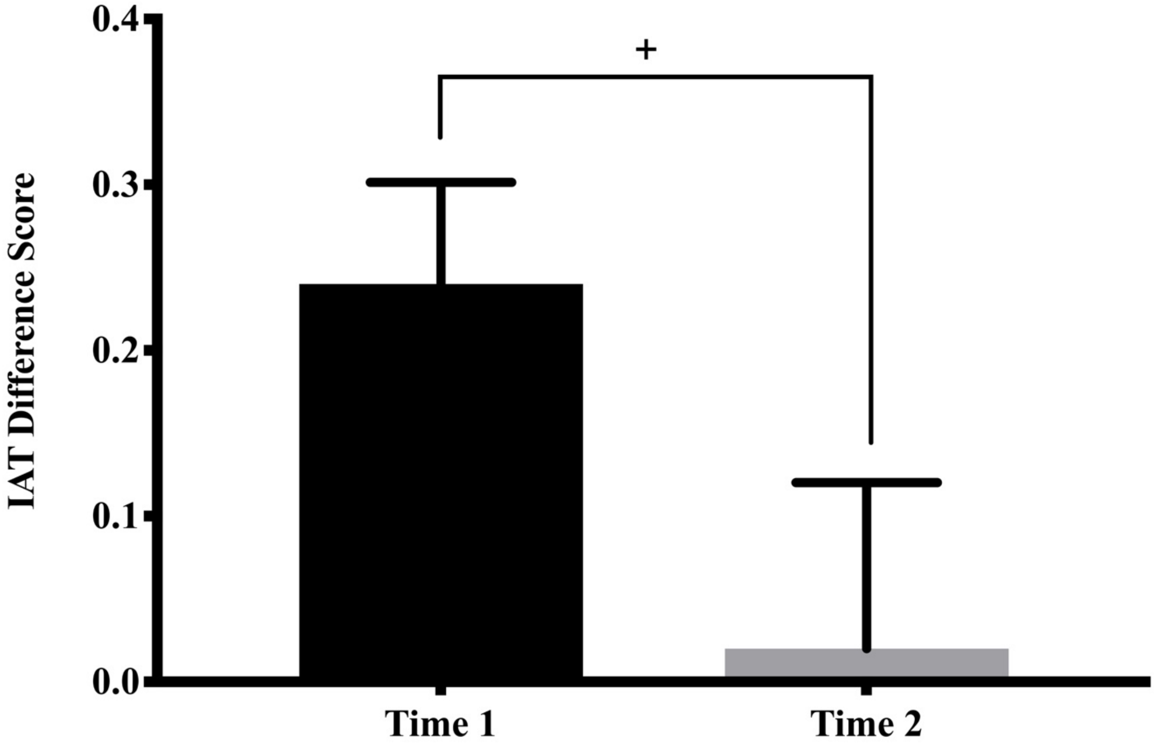

Figure 3. Implicit Measures Demonstrate Improved Self-Esteem. Interleaved bar graphs show calculated mean IAT difference score values with standard error mean for the cohort of STEAMtrix students (n = 22-24) determined using 2-tailed paired Student's t-test, which found marginal (+) effects.

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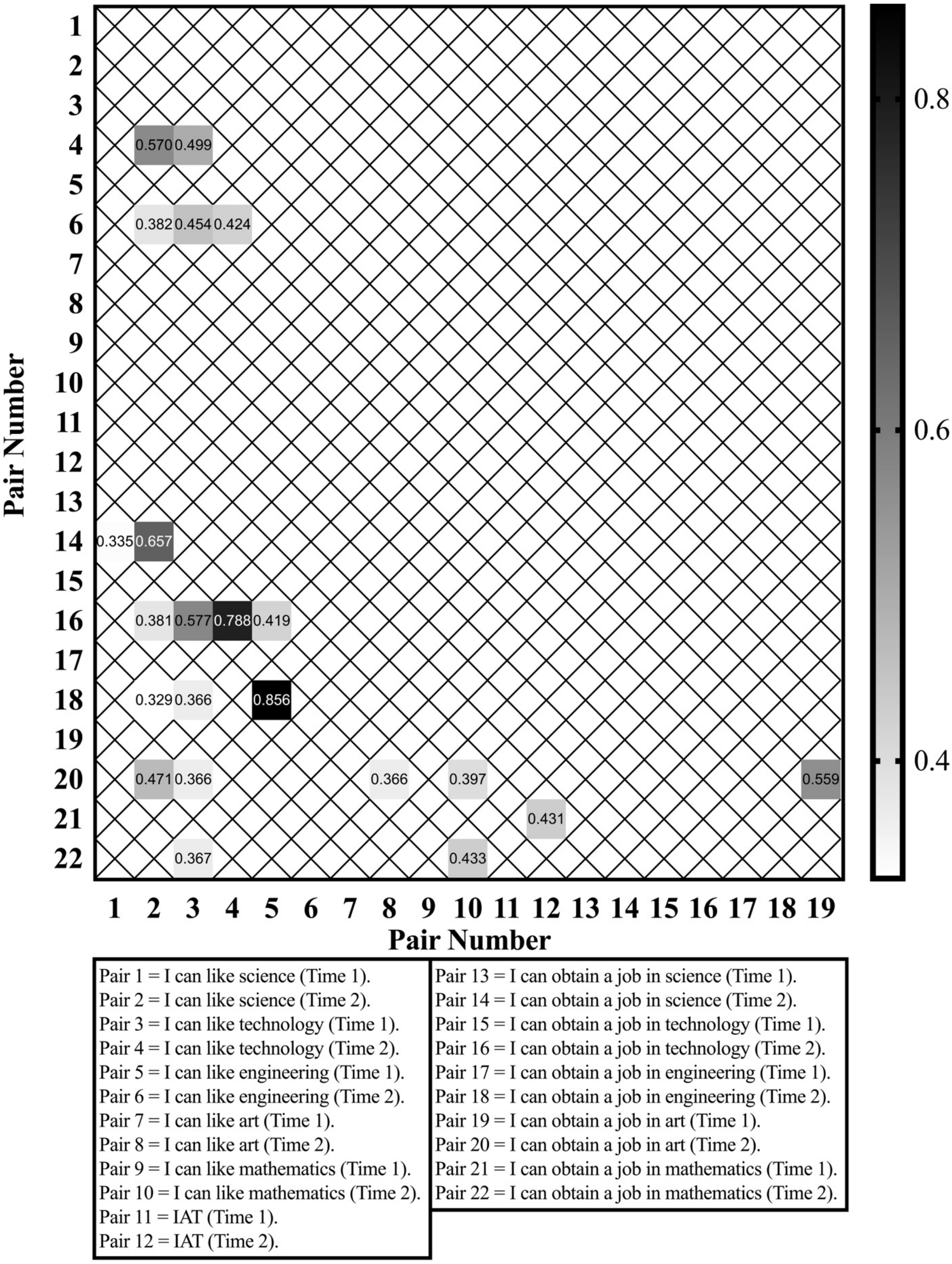

Figure 4. Correlation Matrix. Gray scale heat map shows the relative intensity of values as the correlation between the two pairs for the cohort of STEAMtrix students. In this heatmap the highest values – relative to the other present numbers are black and the lowest are white. Therefore, black squares indicate a strong correlation between the two pairs, whereas white indicates a weaker correlation. Values that did not have a statistically meaningful correlation are blank with an X.

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Discussion

This study was the first to assess the effectiveness of STEAMtrix, a STEM OST education program that incorporates the arts. STEAMtrix was offered as an eight-session summer curriculum at the Salvation Army Boys & Girls Club in Richmond, Virginia's East End to determine if consistent participation could result in the formation of positive STEM-self-efficacy and self-concept in African American students. Our results demonstrate that the pedagogical and curricular features of STEAMtrix increased STEM self-efficacy in some domains such as the self-reported interest in technology as a field and awareness of opportunities to pursue a career in science. In addition, although there were no changes in explicit self-concept as a result of the program, implicit self-concept improved. These preliminary findings, as collectively demonstrated in Figure 4, suggest that pedagogical and curricular features of STEAMtrix, as an example of STEM OST programs that incorporate the arts may have the potential to shift self-efficacy and implicit self-concept, which are some of the most important predictors of educational success (Marsh & Martin, 2011; Pajares, 1996; Valentine et al., 2004).

The current study partially supports previous work demonstrating that when individuals participate in STEM OST programs, their overall interest, capacity, and engagement in STEM rises by an equivalent amount to their participation (Bevan & Michalchik, 2013; Dabney et al., 2012). For example, we found rises in self-efficacy and self-concept from students who regularly participated, and were present for both measures. In the current study, students indicated, compared to Time 1, they were more interested in technology and were more aware of the opportunities to pursue a science, technology or engineering career. These changes in STEM self-efficacy are important as self-efficacy is one of the strongest performance domain factors in academic settings (Hajloo, 2014; Pajares, 1996). Although we cannot over-interpret these findings to suggest they will translate across all STEM programs, providing underrepresented populations in STEM with OST programs such as STEAMtrix may help foster positive STEM-self-efficacy and self-concept.

The finding in our study that implicit self-concept was improved as a function of the program is encouraging, as a positive self-concept is associated with stronger academic performance as well as greater motivation and effort in school settings (Marsh & Martin, 2011; Thomas & Gadbois, 2007). However, as hypothesized, the current study did not find a difference between Time 1 and Time 2 in terms of explicit self-concept. These findings are consistent with previous research demonstrating that interventions targeting groups that are underrepresented in STEM fields improve implicit self-concept but do not affect explicit self-concept perhaps due to ingroup role models as course instructors, guest speakers, presenters and volunteers (Stout et al., 2011). There are also other factors that may have led to these null results including the season, the ages of the population, and the duration of programming. During summer months, most students in traditional academic settings are no longer receiving regular curricular enrichment. During summer months, most students in traditional academic settings are no longer receiving regular curricular enrichment, which may result in lowering of their explicit self-concept baseline and decrease the likelihood of detecting a shift between Time 1 and Time 2.

Therefore, future studies should continue to investigate the effects of interventions that are concurrent with the academic school year. Another explanation for the null results could be the ages of the students in the study. The STEAMtrix curriculum is flexible and can be taught to all within the K-12 stages of the pipeline. Since no students over the age of 13 were included in the study, the data were limited to what could be delineated from younger students. Future studies could address this explanation by including representative populations across the K-12 spectrum. Finally, the acute nature of this study, one day a week across eight sessions may have contributed to the difficulty in identifying a shift within the relatively short time frame of the program. In fact, each age group only had one hour per content area, which is a very short period for instruction and completion of an activity. Studies that follow this framework should continue to investigate the effects of interventions on explicit and implicit self-concept concurrent with regular enrichment, different populations, and

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with longer programs.

Our findings underscore the importance of using both explicit and implicit measures to assess self-concept. Together, our findings suggest that programs such as STEAMtrix can potentially shift both explicit STEM self-efficacy and implicit self-concept. Specifically, these results highlight the impact of pedagogical implications, namely culturally responsive pedagogy and culturally relevant curriculum that is foundational to STEAMtrix. In designing the STEAMtrix curriculum to be culturally responsive, it meets the interests and needs of a diverse group of students. The culturally relevant curriculum is tailored to the experiences of communities to ensure a connection and sense of belonging. Students are provided with foundational opportunities to engage with STEM fields. Importantly, STEM professionals from racially diverse populations serve as examples that it is feasible for individuals from their racial background to be sustained in the STEM pipeline on through STEM careers.

Limitations of This Study

There are several limitations of the current study. First, we were only able to obtain a small sample size.The requirement to turn in paperwork to participate in the STEAMtrix program limited our access to students. Additionally, the small sample size was likely related to some of our marginally significant findings, which may become statistically significant with more statistical power. Second, the nature of the repeated measures design was another limitation in the current study. That is, our results could have been obtained because at Time 2 the students had already completed the measures of interest. Although we think this is unlikely given that STEM-specific self-efficacy and implicit self-concept improved while explicit self-concept did not change, consistent with our hypotheses. However, future research should use a control group with only a post-test to assess causality. Third and finally, the current study only examined able-bodied African American students. There are a number of other underrepresented groups: additional racial minorities as defined by the NSF; women; and those with different abilities (Lehming et al., 2013; National Science Foundation & National Center for Science and Engineering Statistics, 2019). These populations should be included in future studies, and as the focus in increasing representation in the STEM pipeline. In addressing these limitations, future research should attempt to replicate these findings.

Conclusions and Future Study

As a result of the current study's limitations, several questions still remain. First, how does culturally competent pedagogy and problem-based learning intersect in both STEM and art education (Bequette & Bequette, 2012). Second, how can student engagement, learning, and interest be fostered by more integrated art and STEM teaching? Third, what role do STEM OST programs play in student intention to pursue STEM-related careers? In a future study, a STEAM framework can be used to answer lingering questions while analyzing the merit of other OST program models. If used as a model, it is important to note that there will be obstacles in developing programs that meet the needs of all individuals (Grossman & Porche, 2014). Future research using this framework can examine how changes in implicit self-concept can predict future behaviors and intentions to pursue STEM careers (Greenwald et al., 2002). Additional studies can address how students engage STEAM ideas as they are recruited and retained in the STEM pipeline. Within this framework it is important that key components of design thinking in both art and STEM disciplines are conceptualized to isolate overlapping cognitive and procedural dispositions.

Together the results of the current study provide some preliminary evidence that the culturally responsive pedagogy and culturally relevant curriculum of STEAMtrix, a STEM OST education program that incorporates the arts can increase STEM self-efficacy and implicit self-concept (Figure 5). Although this study has important limitations, it suggests that additional research can be done to replicate the current results and examine generalizability to other STEM OST programs. Programs like STEAMtrix could potentially increase interest and awareness of the opportunities in the STEM pipeline, eventually leading to the recruitment, and retention of underrepresented groups, which will strengthen the STEM workforce in the U.S.

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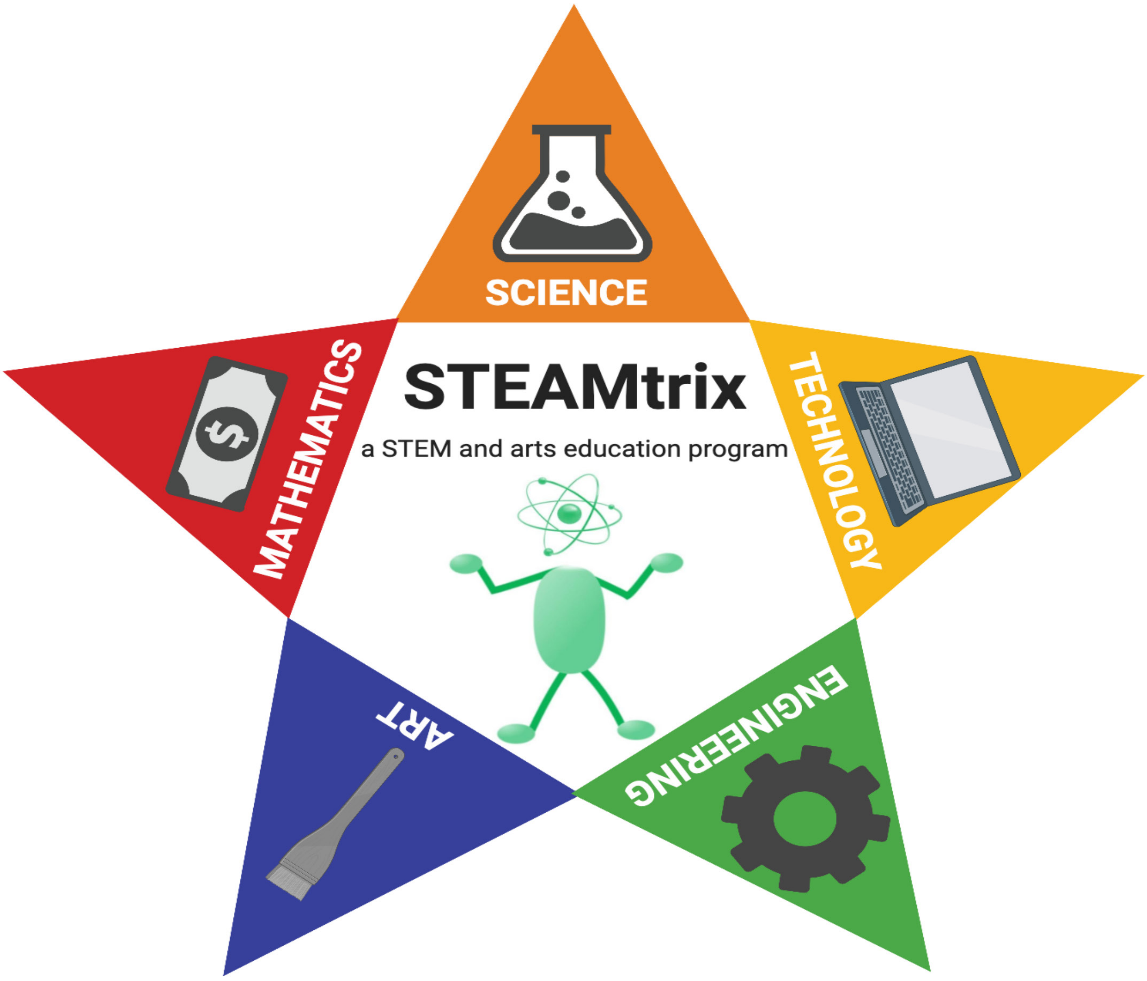

Figure 5. STEAMtrix Summary Figure. STEAMtrix (white), a STEM and arts OST education program is at the intersection of science (orange), technology (yellow), engineering (green), art (blue), and mathematics (red).

Disclosure Statement: Merci N. Best and Robin R. Best declare that they are the co-founders of STEAMtrix. Merci N. Best is also the founder of STEAMKITX. This work was not funded by either organization. Cheryl L. Dickter declares that she has no relevant or material financial interests that relate to the research described in this paper.

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RESEARCH REPORT

Recruitment of Science and Mathematics Teachers: Findings from Three Years Efforts of a Recruitment Program

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Abstract: *Across the US there is a shortage of highly qualified science and mathematics teachers. To alleviate the problem, Federal, state, and local government and agencies have been enacted to improve the quality of education while reducing teacher shortages. Consequently, many agencies, such as the NSF, the U.S. Department of Education, and the U.S. Department of Energy, to name a few, have awarded large grants to universities and other organizations to implement mathematics and science teacher recruitment programs and prepare teachers to deliver high quality instruction. These programs vary greatly in terms of their target populations, the type and frequency of the early teaching experience provided, the academic and financial support systems, and the public relations campaigns. Given the urgency of the national mathematics and science teacher shortage and the high cost of these programs, examining their impact is critical. In this paper, we present findings from three years' efforts of a science and mathematics teachers recruitment program to start mapping the landscape of teacher recruitment. Our discussion and implications suggest that more strategic efforts are need while recruiting students, especially minorities, at all career levels (direct from high school, transfer from community college, change of major, and career changers).*

Keywords: *Teacher shortage, recruitment, science and mathematic teachers*

The Shortage of Science and Mathematics Teachers: Alive and Well

The shortage of qualified science and mathematics teachers (SMT) is not a new problem in the United States (U.S.). Schorling documented this shortage, especially in secondary schools, as early as 1947 and in 1985, Levin reaffirmed that the severity of the shortage had been existed for decades. However, it is in the last two decades that securing a sufficient force of highly qualified SMT to staff U.S. public schools has become one of the most pressing concerns in education groups across the country (Barth, Dillon, Hull, & Higgins, 2016; Goldhaber, Lavery, & Theobald, 2015). According to Barth et al., fewer students are entering to teacher education programs and enrollments in traditional and alternative programs declined by 30 percent between 2010 and 2014. The reasons for the severe SMT include, but not limited to, aging of the current teaching force, low-salaries, class-size reduction initiatives, teacher attrition, and the increased number of science and math credits many school districts require for high school graduation (e.g., Feistritzer, 1998; Haberman, 2001; Ingersoll, Merrill, & Stuckey, 2014; National Center for Education Statistics, 2005; Podolsky, Kini, Bishop, & Darling-Hammond, 2016; Schaefer, 1999; Struyvena, & Vanthournout, 2014; Teitelbaum, 2003; U.S. Department of Education [USDOE], 2001). In addition, as Newton et al. (2010) point out, recruiting highly qualified college graduates with a major in a STEM field is a challenge due to the

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myriad of non-teaching STEM careers that offer a significantly higher starting salary than teaching.

The shortage of SMT impacts the quality of teaching that K-12 students experience. Reported percentages vary slightly, but they all indicate that only a small fraction of the nation's SMT hold a degree in their teaching fields (Committee on Science, Engineering, & Public Policy, 2007; Ingersoll, 1999; Goldhaber et al., 2015; National Academies of Sciences, Engineering, and Medicine, 2015; USDOE, 2000). Another aspect of the teacher shortage problem is that it exacerbates social injustices as it is most marked in high poverty schools, high minority urban and remote rural schools (Ingersoll & May, 2011, 2012). For example, 30% of the SMT who take positions at urban schools end up leaving the profession within their first three years and those who stay oftentimes adjust by doing the minimum to get by (National Commission on Teaching and America's Future, 1996). A recent survey study conducted in the state of Georgia with over 53,000 educators on the possible reasons for this attrition affirms Ingersoll and May's findings. According to the study, 44% of newly hired Georgia teachers dropped-out of the profession by year five. This attrition rate is more worrisome considering that there was a 16% dip from 2010 to 2014 in the number of candidates entering Georgia's teacher preparation programs (Georgia Department of Education [GADOE], 2015). As a result, the teaching force, especially in math and science, in high poverty and urban schools is of dramatically lower quality than that of high affluent neighborhoods where teachers' tenure is longer (GADOE, 2015; Ingersoll, 1999, 2002; Ruhland & Bremer, 2002; Stoddart & Floden, 1995). A similar trend occurs in lower-track classes, where most needy and low achieving students often end up having the least effective teachers (Lynch, Kuipers, Pyke, & Szesze, 2005).

Policies and Programs to Recruit Science and Mathematics Teachers

To cope with teacher shortages, Federal, state, and local government and agencies (e.g., NSF, USDOE, States, and local school districts) have acted through policies and programs focusing on increasing recruitment, retention, and quality of teachers. One policy implemented is alluring potential teacher candidates with financial incentives, such as increasing benefits and scholarships (Education Week, 2000; Kirby, Darling-Hammond, & Hudson, 1989; Liou, & Lawrenz, 2011). For example, the federal government allocated scholarships (e.g., Robert Noyce Teacher Scholarship and the Teacher Education Assistance for College and Higher Education [TEACH] Grant Programs) and teacher loan forgiveness programs (e.g., Stanford Loan Forgiveness for Teachers and Teacher Cancellation for Federal Perkins Loans) to states to help districts recruit, train, and retain quality teachers. However, neither these policies nor traditional teacher education programs have been able to promptly produce enough SMT. The federal government has also allocated grant money to a wide range of programs to improve the quality of teaching and make the teaching profession more attractive to current and potential new teachers (e.g., Improving Teacher Quality State Funds, Transition to Teaching, Teacher Incentive Funds, etc.). In 2013, for example, Congress appropriated $2.9 billion for these teacher programs (Atlas, 2013). Many of these financially supported teacher education programs expose qualified undergrads to teaching experiences (e.g., the University of Texas-Austin UTeach program).

More intense alternative certification policies have also been implemented. By 2015, forty-eight states and the District of Columbia had implemented at least one such program (USDOE, 2015). For 2017 fiscal year, USDOE requested $12.9B for the TEACH Grant program that awards annual grants of up to $4,000 to eligible undergraduate and graduate students who agree to serve as full-time teachers in mathematics, science, foreign language, bilingual education, special education, or reading at a high-need school (USDOE, 2017). In 2013, for example, USDOE awarded six grants totaled about $30M for teacher recruitment. Teach for America (TFA) program, which is an alternative program, was one of the six awardees. TFA planned on preparing 12,500 new teachers over the two years following the award. Even with all of the government funding for recruitment, the issue remains unaddressed as both universities and alternative teacher licensure programs continue to find it difficult to recruit prospective mathematics and science teachers. And the success of the policies and programs implemented has met with mixed reviews (Cavanagh, 2007). Thus, it may be the time to examine the issues associated with recruitment of SMT.

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Why People Choose Teaching as A Profession?

There are a wide variety of reasons for choosing a teaching career. These factors may include a sense of vocation, an initial long-term commitment to the profession, or the influence of specific people on the future teacher's career decision as well as unpredictable (e.g., pregnancy, unemployment) and contingent factors (e.g., geography). Research suggests that the motivation to pursue a teaching career may fall into three categories: (a) altruistic reasons, such as enjoying working with children and contributing to society; (b) intrinsic reasons, such as studying subject matter, academic development, and engaging with the activity of teaching; and (c) extrinsic reasons, including, pay, social status, work schedule, and working conditions (e.g., Brown, 1992; Brown & Butty, 1999; Chuene, Luben, & Newson, 1999; DeLong, 1987; Eick, 2002; Heinz, 2015; Howes & Goodman-Delahunty, 2015; Stokes & Tyler, 2003; Wang, 2004). To illustrate, in a study in which Kyriacou and Coulthard (2000) compared the views of teaching held by undergraduates found out that undergraduates definitely did not consider teaching and only cited extrinsic factors such as good promotion prospects and 'high earnings over length of career' as important. The undergraduates who were attracted to teaching viewed characteristics such as 'a job that gives me responsibility' (intrinsic), 'a job where I can contribute to society' (altruistic) and 'job mobility' (extrinsic) as important in their future career.

Early exposure to teaching, whether in formal or informal settings, is identified as a prominent factor on career decision of those who were (dis)interested in teaching or may have not thought about teaching as a career option (e.g., Taylor, 2006; Tomanek, 1996; Tomanek & Cummings, 2000; Valadez, 2003). Apparently, the factors influencing teaching career decisions are more embedded in the socio-cultural contexts. In the U.S., King's (1993) and Valadez's (2003) studies revealed that society negatively influenced the decision to become a teacher. Lack of prestige, poor working conditions, and media reports on negative issues in teaching were some of the societal factors recognized by research participants. However, in Taiwan, Wang (2004) reported positive societal influences on the research participants' teaching career choices. Results illustrate that favorable government policies, cultural beliefs about teaching, appealing working conditions, and the high social status of teaching attributed were some of the reasons cited by the research participants for choosing teaching as a career. Finally, the Watt and Richardson's (2007) framework summarized the factors mentioned above and also included the positive influences of prior learning experiences, individuals' perception of teaching in terms of task demands and returns, self-perception of teaching ability, and a fallback career construct which accounts for individuals who have been unable to pursue their first-choice career or who were unsure of their career choice and defaulted to teaching careers.

Effective Teacher Recruitment Strategies

The reasons for selecting a teaching career posited in the previous section helps explain why school districts and universities use certain recruitment strategies to attract individuals into teaching. Research on successful methods for recruiting teachers into science and mathematics (Garibaldi, 1989; Howes & Goodman-Delahunty, 2015; Liou, & Lawrenz, 2011; Oakes, 2001; Sears, Marshall, & Otis-Wilborn, 1994; Tomanek, 1996) can be summarized into five strategies: recruitment campaigns, early exposure to teaching, academic support systems, financial support systems, and public relations.

Recruitment Campaigns

Campbell and Spiro (1982) found that newspaper ads and direct mailing were the most cost-effective means by which to reach potential students. While radio ads were relatively low in cost, only about 9% of their survey respondents (n = 255) heard about their continuing education program through radio ads. Television advertisement was found not to be cost-effective at all. Details as to the extent of use of each of the advertising mediums were not provided. Berger and Wallingford (1996) suggested that more personal outreach efforts can be effective, such as open houses, advertising specialties like calendars with important dates for applying included, and direct mail of promotional items, such as brochures or flyers. According to Abell et al., (2006) and Demir, Martin-Hansen, Gul, & Puvirajah (2012) digital media platforms, e.g., Facebook, provide excellent outreach with which

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to recruit teachers.

Opportunities for prospective and current student teachers to interact with those who are in teacher education seem to have positive impacts on one's decision to pursue a career in teaching. According to Wright and Custer (1998)'s study, the number one factor was interaction with university faculty (37%), followed closely by being impressed with facilities at the university. The least effective means of recruiting was a personal letter from someone currently in the teacher education program (6%). When recruiting from minority groups, Kim (2006) found that interaction with faculty and the presence of role models who reflect the groups' ethnicity were effective recruitment methods. Carrier and Cohen (2005) and Littleton (1998) noted collaboration between colleges and school districts increased the number of mid-career people who return for licensure specifically to teach in urban settings. The pool they tapped included substitute teachers and paraprofessionals or aids who already worked in urban schools.

Early Exposure to Teaching and Field Experiences

Prior positive teaching experiences (no matter how informal), career opportunities, and the perceived possession of personal attributes beneficial to teaching are found to be positive motivators to pursue teacher education. Hammond (2002) reported that pre-service teachers credited their previous positive experiences with teaching, mentoring, or guiding students as most influential in their decisions to become teachers. Teacher candidates argued that the experiences provided them with new confidence, purpose, fulfillment, and an appealing introduction to inquiry-based learning. Jenkins (1998) found that, in occasions, initial choice of a science teaching career included reasons such as simply trying out teaching as one possibility among many. Numerous university-based recruitment programs (e.g. the Science Majors as Teaching Interns Project, Tomanek & Cummings, 2000; the Oregon Collaborative for Excellence in the Preparation of Teachers, Enneking, 2003; the Teaching Scholars Recruitment Initiative, Shulman & Armitage, 2005; and GK-12 programs, Trautmann, 2008), offered STEM undergraduates pedagogical training along with K-12 or college teaching experiences. A common finding was that the participants claimed significant contribution of the teaching experience for recruitment purposes, as they increased their interest, passion in teaching, and knowledge of teaching's demanding realities. Those experiences were also helpful to those who had initially thought about teaching; then decided not to pursue teaching as a career. These participants cited the demands placed on teachers, the high needs of students, and the lack of cooperation on the part of parents as their reasons for choosing alternative careers. However, given that the programs include other components along the teaching experience, it is uncertain that the reported effect of increased interest in teaching careers is solely the consequence of the teaching experience.

Academic Support

Academic support structures provided by universities, such as advising, student professional organizations, and learning communities are important considerations in recruiting teachers (e.g., Clewell & Forcier, 2001; Jacullo-Noto, 1991; Villegas & Davis, 2007). Villegas and Davis uttered that, once admitted to a teacher education program, prospective teachers need to receive academic support services for retention and a timely completion of their program, e.g. support with steering the complexities of the higher education bureaucracy.

Financial Support

Research indicated that financial assistance is a positive element in making the decision to enroll in a particular school or program as opposed to another. Yet, according to Berger and Wallingford (1996), prospective students must be in the advanced stages of decision-making which is the conviction stage (see the six stages model for commitment by Kotler & Armstrong, 1991) before scholarships and other financial incentives are influential. They found out that in the conviction stage, the students placed the institution or program at or near the top of their choices. Financial assistance, therefore, is more attractive after much of the recruiting efforts have been set forth.

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Public Relations

Sinclair, Dowson, and MacInerney (2006) found that the most common motivators for one to pursue teaching included the desire to work with children, the value placed upon teaching, intellectual stimulation, and helping others. They did not, however, find that ease of entry and work dissatisfaction with previous employment to be strong motivators for selecting teaching as a career. These findings are oftentimes used to develop public relations strategies that aim to attract students to teaching who place high value on working with children and helping others. Common public relations strategies are found in public service announcements run on television and radio, as well as in ads in local newspapers, regarding the personal satisfaction associated with working with children and teaching.

Purpose of the Study

Many teacher recruitment programs around the nation are facing the challenge to attract qualified candidates into science and mathematics teaching. Therefore, a study of how these aforementioned motivators operate to prompt an individual to pursue a teaching career would help to make these programs more efficient. This paper aimed to further our knowledge about: (a) promising recruitment strategies; (b) characteristics of science and mathematics teacher candidates in the Teach Science & Math (TSM); (c) factors contributing to those candidate's decision whether to pursue teaching career; (d) candidates' entry points to the TSM. We believe that construction of these characteristics makes a meaningful contribution to the existing knowledge base of teacher education and provides useful directions for recruiting future science and mathematics teachers.

Context of Study

The TSM was a federally funded science and mathematics teacher education recruitment program housed at Midwestern university. It was developed on the basis of existing research-based literature and modeled after other successful programs (e.g. UTeach in Austin, Texas). The TSM program was designed to recruit, better prepare, and retain SMT for urban schools. TSM recruited potential teacher candidates from a pool of high school seniors/pre-college students as well as professionals who sought a career change. The TSM provided the opportunity for professionals with strong mathematics or science content backgrounds to earn a teaching license and master's degree in less than two years. The program was a multi-leveled partnership among four colleges at the university where the TMS program was situated (the Colleges of Education, Arts and Sciences, Engineering, and Pharmacy), the local public-school system and the local Catholic school system. Additional supporting partners included the city zoo, the city science center, and a few other community organizations that offered exposure to teaching children.

The TSM Recruitment Efforts

Those undecided potential candidates in their career choice were encouraged to explore teaching as a profession. For example, only about a third of the freshmen who enter the College of Pharmacy continue to the upper division. Many of these students, having completed several courses in chemistry and other sciences, may explore the possibility of becoming a high school science teacher. Similarly, recent graduates with Bachelor of Science with majors in a mathematics or science disciplines were also encouraged to consider coming back to retool for a teaching career. Thus, the goal was not to take students from other colleges who "wash out" of their programs, but rather to better inform students early in their Freshman year of career possibilities in teaching, attract students from the aforementioned fields who are better suited for teaching, and who have stronger interests in teaching than they originally thought when they enrolled in these other colleges. Therefore, at the outset of implementing the program, TSM recruitment efforts were centered upon five successful research-based strategies (recruitment, early exposure to teaching, academic support systems, financial support systems, and public relations) for recruiting and retaining potential teacher candidates into urban science and mathematics teaching described erstwhile. A dedicated recruiter was hired to assist with those recruitment efforts and hosting and facilitating open houses. Following, we provide a brief description of these key components utilized in the TSM program.

Early Exposure to Teaching

TSM students were introduced to teaching during a 3-week residential Summer Institute and a 6-week academic year initiative. The experience was specifically designed to acquaint talented minority pre-college high school students (incoming junior or senior) with the practical aspects of teaching and create opportunities for academically talented students to interact with successful science and mathematics teachers. During the summer institute, participating TSM students were given opportunities to: (a) interact with master teachers and college professors; (b) plan science and mathematics activities; (c) teach younger students in classroom and community settings using teaching strategies and activities they learned about in the program; and (d) discover if science or mathematics teaching profession was right for them. Following the summer institute, students continued to be a part of the program for another six weeks during the school year. Meantime, the TSM program provided paid internships for prospective undergraduate teacher candidates to engage in applied work experiences in science or mathematics fields. The internships were for 10 hours per week and could be renewed up to two semesters. Students had an opportunity to work with urban youth in settings such as the city Zoo, the city science center, the university's planetarium, the local Boys and Girls Clubs, and other community agencies.

Academic Support Systems

The Exploring Urban Mathematics/Science Teaching (Exploring) Course was developed to recruit high quality STEM undergraduate students and graduate students interested a career change. This three credit-hour course was first offered during the Fall semester of the Year 1 and throughout the TSM program. The TSM program paid the tuition for students who took this course, in which the average enrollment was 15. Though the course design improved knowledge and skills for teaching, it was also designed to give participants an early field experience with teaching in an urban environment. It provided students with background, training, tools, and practice prior to allowing them to actually teach. Much time was spent observing teachers (both video and direct observation), participating in a case study of teaching, discussions about and exploration of different teaching styles and approaches, the unique aspects of teaching in an urban school (e.g. working with students who had limited English language skills, who were at risk for academic failure, who came from low socioeconomic backgrounds, and who represented a variety of ethnicities) and student journals about what they were observing and learning about teaching. Additionally, the course allowed students to experience innovative technologies used in the classroom. Most importantly, it provided a context to candidates to determine through self-analysis if the teaching profession was right for them.

Public Relations

The TSM employed several public relations strategies to help communicate the importance of becoming a science or mathematics teacher and recruit potential students to the program. A website was created to provide information to both prospective students and the people who were associated with the program (e.g., teachers, principals, advisors). Additionally, a monthly newsletter was sent to area schools and community leaders. The newsletter typically included information about the program and success stories about the graduates. Finally, there were several 30 and 60-second radio and TV Public Service Advertisements designed to interest students in taking science and mathematics in school as well to recruiting teachers into science or mathematics teaching.

Financial Support Systems

Besides tuition waiver for the Exploring course and paid internships, the TSM program worked with the university Financial Aid Office to identify scholarships, grant, and loan forgiveness programs to assist students with financial issues. Students were made aware of the Federal Loan Forgiveness for science and mathematics teachers if they taught in high need/low income school districts that were listed in the Annual Directory of Designated Low-Income Schools for Teacher Cancellation Benefits. With U.S. Department of Education funding, the TSM program also provided students with up to $12,800 in financial assistance (in the form of financial aid or merit scholarships). Students who received Financial Aid and Merit Scholarships had to agree to teach in high need

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schools for the length of time they received financial support. Otherwise, they were required to repay the money to the U.S. Department of Education.

Methodology

We used a holistic single-case study approach (Yin, 2013) to study recruitment efforts of science and mathematics teachers to the TSM program. Case studies are used to explore bounded systems such as an event, process, or program that we have no in-depth perspective about (Yin, 2013). Thus, the case study method allowed us to retain the holistic and meaningful characteristics and decision points of those who were thinking about science or mathematics teaching as a career and those who were recruited to the TSM program in the first three years.

Data Collection

We employed multiple sources of data, as in the use of questionnaires for carrying out a survey, semi-structured interviews, archival records and documents (e.g. student records, program files, e-mails, open-house data such as surveys and signing sheets, and inquiries). Data from those multiple sources provided information about the circumstances that surrounded potential applicants' interest in becoming science or mathematics teachers, parts of the TSM program they found to be attractive, how they learned about the TSM program, and what, if anything, prevented them from enrolling in the program.

The TSM's archival data set consisted, but not limited to electronic records (such as follow-up emails); Exploring course enrollment; old-fashioned (paper) files; recruitment materials (such as brochures, electronic media, new paper ads); information on those who did not enroll to the program and those program participants' demographic and background information (e.g. degree obtained, year of graduation, current careers, they knowledge of the TSM, how did find out about the TSM etc.); and open-ended questionnaires/surveys (Open House and Thoughts about the Teaching Profession questionnaire). The resulting archival data were both quantitative and qualitative. Open house questionnaire included nine open-ended questions focusing on the issues of recruitment and respondents' reasons for career choices, especially teaching (see Appendix A). From the four open house events spanned over the last two years of our data collection, we collected data from 41 participants. Thoughts about the Teaching Profession questionnaire was administered only to TSM' newly admitted students at the beginning of the program. The survey focused on the participants' disposition towards teaching and learning (see Appendix B for sample survey items). Data obtained from 63 TSM participants using this questionnaire. There was any overlap between the two sets of the participants as there was only one student recruited through Open House efforts over the years period (see Table 2).

To acquire more substantial information on the issues of recruitment, participants' decisions and decision points on choosing a teaching career either in science or mathematics, and the TSM program structure and recruitment efforts, we conducted 10 semi-structured interviews (Seidman, 2015) carried in a conversational mode with a subset of Exploring course participants (see Appendix C for sample interview questions). These interviews were used to complement open-ended surveys used at different stages of the program. Each of these interviews lasted between one hour and half to two hours. Participants were randomly selected among the 87 Exploring course participants. Once selected, they were extended an invitation to participate in the research study. Participation was voluntary and consent form detailing study purpose and procedures was provided to each research participant. The participants' construction of reality provided important insights into the case.

Data Analysis

The availability of multiple data sources produced an imperative opportunity for triangulation, as we were able to continually check and recheck the consistency of the findings from different as well as the same sources (Yin, 2013). This allowed us to establish converging lines of evidence in making our findings as robust as possible. Our data analysis began by systematically organizing our data (narratives and words) into hierarchical relationships, matrices, and creating tables to present both qualitative (narrative) and quantitative data in the cells of tables (Miles & Huberman, 1994). Our analysis did not start with any predicted patterns, but in fact it started with open-ended research questions that lead to the use of an explanation-building technique (Yin, 2013). With regard to this approach, when the data set was complete, Thematic Analysis was used as our first coding method to define the significant elements of our open-ended research questions and to check the alignments of the research questions. In pursuit of this, to reorganize and reanalyze the data, we used Pattern Coding as a second cycle coding method (Saldaña, 2013). This enabled us to distill and pull together the primary categories into a more meaningful and parsimonious unit of analysis (e.g., impact of the Exploring Course). The analysis concluded with carefully constructed analytic generalizations of our findings. In doing so, we attempted to show how our study's findings informed the relationships among recruitment strategies utilized by the TSM, participants' decision on entering the teacher education program or not entering, and the TSM's program components effect on the recruitment and retention.

Findings

The original TMS program's focus was on recruiting students at all career levels (direct from high school, transfer from community college, change of major, and career changers). As a result, staff and resources had been spread very thin in an attempt to produce and distribute a variety of literature in print and electronic form, talk to school counselors, send staff to various campus events such as Freshman Orientation and Undecided Majors Fairs in addition to the myriad of other strategies used (showed in Figure 1). As an outcome of those recruitment efforts, the number of inquiries made about the program went up from 65 in year one to 199 in year two, and to 246 in year 3 (See Table 1 for detailed information).

Table 1.
Results: Total Inquires Made to the TSM by the end of Year 3

Source of program fall and spring information	Number of Inquires		
January to December	Year 1	Year 2	Year 3
Personal contact	53	157	154
Advisor/faculty	33	79	90
Friend/classmate/family	5	12	23
Contact UT/COE/UT3 office	7	13	12
High school teacher/counselor	1	2	4
Referred by another university		4	
Quest-Undecided students	1	1	1
The Source		6	
UT3 presentations			
Majors Fair	1	5	12
Rocket Launch	5	5	
Open House		2	3
EXCEL program/TUMSA		1	3
Freshman Orientation		1	1
Career Day		2	2
Masters Presentation		4	3
Internet (Website/email)	4	6	19
Letter/Card in the mail	3	4	5

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Media	2	32	54
Sign/Flyer		2	6
Radio/TV		1	1
Newspaper Ads (Blade, local papers & UT News)	2	29	40
Toledo Blade Article			7
Unknown	3	20	14
Total	65	199	246

By the end of year 3, a total of 57 students had been recruited. However, as shown in Table 2, there was a decline in the number of recruited students, 20 students in year one, 20 students in year two, and 17 in year three.

To be accepted into the TSM, students had to meet both the college and the program's admission requirements. By the end of year three, 125 applicants submitted applications. Of these applications, only 89 were complete to be reviewed by the program's scholarship committee. The remaining 36 applicants did not complete their files to be considered for full review, though the program coordinator and staff made several attempts to each individual to remind them of their incomplete application files. The scholarship committee awarded 76 applications after a detailed review. Fifty-seven of these applicants, including 4 people who dropped out from the program by the end of spring semester in year three, enrolled to the program.The 19 applicants who were awarded scholarship, but did not enroll to the TSM decided to not pursue a career in teaching for a variety of reasons such as change in major, finding a job, or program length. On the other hand, the 13 applicants who were rejected for scholarship by the committee because of a range of reasons, such as low GPA or indication of low commitment for teaching profession, were not declined permanently. Depending on their circumstances, they were offered some alternative pathways, e.g. either to take the Exploring course or an internship and advised to reapply afterwards, or, if they had low GPAs, then they were asked to reapply once they met the College of Education's requirements.

Table 2.
TSM Students (subset from Table 1)

Source of program information	Number		
Enrolling in School Year/Receiving $	Year 1	Year 2	Year 3
Personal contact	17	19	15
College Contact - Advisor/faculty	14	10	10
Friend/classmate/family	3	4	5
High school teacher/counselor		2	
UT3 presentation		1	
EXCEL program		1	
Internet			2
Letter in the mail	3		
Newspaper		1	
Total	20	20	17

By the end of spring semester in year three, 87 students had taken the Exploring course (59 students seeking undergraduate degrees while 28 of them were seeking master's degrees). Nineteen of these students had been accepted to the program, and 16 of these students were required to take the explore course, so they could explore teaching and learning of science and mathematics before making a commitment. The course was originally intended as a recruiting mechanism for undecided students through early field experience with teaching, yet it turned out to be a confirmatory experience. Even majority of the students, who decided not to pursue teaching as a career, recognized the

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benefits of experiencing real teaching environment (e.g. pros and cons of teaching), some hesitated to participate to the TSM due to a long-term commitment after graduation. For instance, during an interview with Nate, he argued, "I don't really know what I want to do directly after graduation. The main problem I have with [TSM] is the length of the commitment. The only thing I heard about it was like 5-year commitment after college." Contrarily, interviews and surveys conducted with those students who had made their mind about becoming either a science or mathematics teacher indicated that the course served as an assenting tool and the financial support that was not an influential factor in their decision. To them, financial support was a bonus. Furthermore, the course served to those committed students as a mean of exploring urban teaching. To illustrate, "It gave us the opportunity to really look and see like how teachers can be and what we want to be and how we don't want to be towards the students and stuff...I had my heart set on teaching," stated Angela. Those committed students typically took the course to develop a greater confidence in their decision to teach and to broaden their comfort zone by exploring urban teaching in particular. For example, Daniel, in an interview before he taking the course, stated, "Becoming an urban teacher would definitely be very difficult just because of motivational issues really. Students don't care to learn and to do well." During the course, Daniel realized that positive rapport and meaningful pedagogical practices were some of the key factors in connecting with students. "I found out that teaching is really more than just talking to students. It's about interacting with students and getting them do hands-on things, apparently that's huge," said Daniel. Thus, those students who were attracted to the course were not undecided about teaching as a whole, but tended to be undecided about whether or not they wanted to be urban educators. Data collected from these students also revealed that they tended to agree more at the end of the semester that teacher education is more important than a natural teaching ability in the development of good teaching practices.

The survey, entitled Thoughts about the Teaching Profession, was administered to the TMS programs' newly admitted students. Results provided interesting information regarding student's dispositions. Of the total 63 respondents (9 from Exploring class and 54 from orientation group) to the survey, 49% said that a desire to help others was the reason they decided to pursue a teaching career. Thirty-three percent indicated they wanted a career where they could work with children and 27% said that they had some teaching experience and loved it, early exposure to teaching.

Data collected via interviews and surveys, including incomplete applications and open house data, revealed that previous positive teaching experiences were the most common characteristics of all induvial across the board. It did not differentiate whether they enrolled to the program either at undergraduate or graduate level or inquired about the program. For example, 32 of 41 people who participated in open house surveys in the fall Year 1 and sprig Year 2 indicated that they had some prior teaching experience, such as through tutoring, law firm, and summer camp (see Table 3). Similarly, all students who were enrolled to or had graduated from the TMS program, except two, indicated that they had some previous teaching experiences (see Table 2).

Table 3.
TSM Students' Responses to Open House Questionnaire

Questions		Number of Input
Whose opinions do you care about in terms of your choice of career?		68
My own	33	
Family	19	
Teachers	6	
Friends	10	
When did you first think about becoming a teacher?		45
Elementary school	6	
Middle School	4	
High School	10	
College	11	
Graduate School	4	
Other jobs	10	
At this point, how committed are you to pursuing a teaching career?		40
Seriously considering	30	
Possibly considering	10	
Why are you interested in becoming a math or science teacher?		37
Like teaching to youths	9	
Enjoy science/math	14	
Feel strong in math/science	5	
Have enthusiasm in teaching (to make a difference)	12	
Career change	3	
Need qualified teachers in math/science	4	
Have you had any prior teaching experience such as tutoring, Sunday school, teacher aid, teacher assistant, etc.?		40
Substitute teacher in high school	10	
Tutoring	12	
College teaching	8	
Sunday school	4	
Teaching assistant	6	
What aspects of math or science teaching are most attractive to you?		37
Like math/science	24	
Make people excited about science	3	
Problem solving techniques	5	
Influence students' future careers	5	
What aspects of math and science teaching are least attractive to you?		22
Boring	2	
Less self-efficacy	6	
Students' lack of interest and behavioral problems	8	
Requirements (i.e., preparation time, grading, homework, standardized tests, etc.)	6	
What strategies you think could be taken to make the teaching profession more attractive?		21
Commitment to help students' learning (i.e., hands-on and interactive strategies)	6 4	
Enjoying and satisfaction of teaching	2	
Parental involvement	5	
Financial incentives	4	
Mentoring teachers		
Is there anything that would help attract you to a teaching career?		27
Financial incentives	11	
Already attractive (by TSM)	10	
Mentor/Support	3	
Programs to fast tracks in becoming teacher	3	
Total		337

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Research data indicated that most of the teacher candidates seriously started to think about teaching either at college –at late stages as junior or senior undergraduate student— or after college while working on other jobs rather than thinking about teaching at earlier ages. This finding was also supported by findings from Excel program (a component of our recruitment whereby high school students attended a summer program about teaching). The Excel portion of the program, which was designed to recruit talented minority high school students to science or mathematics teaching, had resulted in recruiting only on student. Yet, the Excel program reinforced some of those students' existed desire to pursue a career in science or mathematics teaching. Angele said, "I always used to play teacher growing up, so I always had that thought in my head" [interview]. Similarly, Jason claimed, "From all the enjoyment and excitement from teaching in the summer time, I figured why not do this as a year around type of thing." In the first three years of the program, 39 students participated in the summer institute: 15 students in year one, 13 students in year two, and 11 students in year three. Although at the end of year three, we were able to recruit only one student from Excel the data revealed that they enjoyed working with students who were younger than them and they gained a broader view of what science or mathematics teaching entails, e.g. challenges, content knowledge, etc. Excel students' data at the end of the summer sessions unveiled that most of them had already made their minds for other career choices such as pharmacy, engineering and medicine. Interest in teaching, as a career, for those high school students, remained a second or third choice. They cited personal interest and salary as the top two factors that were fundamental to their decision of why they would pursue their career choice.

Lastly, follow up interviews conducted with potential students who requested more information, but did not apply for the TMS program indicated that most were not interested in teaching in a high needs area to fulfill the service requirements of the scholarships. This was especially true with undergraduate students in their first two years of their program. With this in mind, the TSM personnel made some substantial changes in recruitment effort toward target populations, e.g., the TSM recruitment personnel shifted the recruitment efforts to seek candidates who had the dispositions toward teaching, but not necessarily toward urban teaching initially and toward individuals who were either upper division undergraduates or second career Masters-level students.

Discussion, Conclusion, and Implications

This study aimed to further our knowledge about: (a) promising recruitment strategies; (b) characteristics of science and mathematics teacher candidates in the Teach Science & Math (TSM) program; (c) factors contributing to those candidate's decision whether to pursue teaching career; (d) candidates' entry points the TSM. Over the course of the TSM program, we anticipated a greater number of applicants than we were able to recruit. This challenge led us to ask ourselves, "What are the most success recruitment strategies associated with recruiting prospective science and mathematics teachers who want to teach in urban schools?" Thorough examination of the TSM data from year one to year three indicated that most of the individuals who inquired about the TSM program found out about the program through personal contact, including, but limited advisor/faculty, the TSM faculty and staff presentations, friends/classmate/family, contact University/COE/TSM office, etc. (see Table 1). By the end of year 3, personal contact remained to be the most significant method of recruitment.

The open house events included opportunities for prospective teachers to meet with the TMS faculty and students. Findings from the four open house surveys revealed that the majority of attendees, overall, felt the faculty presentations and the question and answer period to be the most informative aspect of the program, including discussion that took place among prospective and the TSM program students. The Exploring course was a great medium not only for proving situated teaching and learning opportunities for the program participants to explore urban science and mathematics teaching, but also enabling them to make their minds towards teaching as a career. The TSM undergraduate participants reported that they gained a better understanding of teaching. They agreed that the Exploring course reinforced their career choices whether to pursue or not teaching as a career (Singh & Billingsleya, 1998). Thus, it can be claimed that the Exploring course acted as an efficient career selection tool for participants to help them make the best choice even before they enter the pipeline. Also, participating in the Exploring course served as platform to the TSM participants as the course seemed to have more of a confirmatory effect rather than a significant recruitment strategy (Moin, Dorfield, & Schunn, 2005).

Regarding informal educational experiences, all students in the TSM program discussed rich informal educational experiences centered around family, community, and/or church (see Table 3). These results indicate that, at least partially, factors that underlie the decision to choose a certain route to certification in secondary science and mathematics (i.e., alternative vs. traditional) and the timing to do so (i.e., later vs. directly after earning a college degree) relate to more distal than proximal factors. These latter factors seem to be mainly related to family background and early formal and informal educational experiences.

While extrinsic motivations were chief among the universe of career changers, these motivations were the main reason for only a portion of the undergraduate population. This population seemed more disposed to consider a teaching career and only when they felt low intrinsic motivation (no interest in teaching) or low altruistic motivation (no interest in teaching at disadvantaged settings) the pursue of a teaching career became unlikely. Intrinsic and altruistic reasons include trying teaching and more involvement in the discipline (intrinsic) and working with children and helping others (altruistic). Based upon these findings, we targeted our outreach to emphasize or provide opportunities to experience the rewarding aspects of helping others to learn and working with children or adolescents. This outreach included participation in the Exploring course. By the end of year three, we promoted these ideas in newspaper advertisements aimed at prospective students who were invited to one of two open houses.

Over a three-years period of recruitment efforts, we observed some challenges with recruiting SMT for urban schools that were either associated with the TSM recruitments efforts or as a results of external factors, e.g., college admission recruitments, personal factors, policies, etc. The most prevalent challenges included: a) recruitment of minority participants; b) college credit and admission requirements; c) logistical factors for undergraduate students; d) ceiling for recruitment; e) service requirement; and f) timing. It was a difficult task for the TSM program as it mostly targeted the white population.

Recruitment of minority participants. Despite the TMS's purposeful targeted recruitment efforts to recruit minorities through minority churches, schools, newspapers, neighborhoods, etc. the outcomes were not at desired level that the TMS program wished to have.

College credit and admission requirements. For the TSM, education requirements both from the College of Education to attain teaching certification and from disciplinary courses to complete content credit requirements for a master degree, were a deterrent to potential candidates.

Logistical factors for undergraduate students. While low teacher salaries were a deterrent factor for career changers, it did not seem to be a factor for undergraduate student population for participating in the TSM's recruitment efforts. For them, common barriers for program participation were logistic in nature (such as missing the deadline and scheduling conflicts). A fair number of undergraduates who attended informational events, but did not apply to the program reported lack of time for participating in the program. This last aspect may suggest that these individuals might have other career priorities such as research or application, and teaching may have been their fallback career (Watt & Richardson, 2007).

Ceiling for recruitment: The assumptions that there are a lot of people out there that can be recruited for integrating the science or mathematic teaching force seems to be incorrect from our experience, especially minorities and urban teachers. This seems to be the case for the TSM program as well. Although the TSM recruitment efforts increased and expanded more strategically from year 1 to year 3 the number of teacher candidates who were recruited decreased. This finding is in agreement to previous findings of Moin et al. (2005).

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Service commitment. The federal government required a year of service in a high need school for each year the student received a scholarship. This was perceived as impediment both by undergraduate students and career changers. While undergraduate students did not want to make long-term teaching commitments potential teacher candidates, on the other hand, were not interested in teaching in a high needs area to fulfill the service requirements of the scholarship. Thus, the scholarship tended to be a more attractive enticement to those students who have entered the program with fewer years of service commitment.

Timing. From the undergraduate population, the late undergraduate years seem to be the time when more candidates are interested in the participating in a recruitment program. The TMS programs did not have high recruitment of freshmen and sophomores. This finding is in agreement with Moin et al. (2005) who concluded that upper level STEM undergraduates are a more appropriate target for teacher recruitment efforts compared with freshman and sophomores. Similar results were observed with Excel Program, designed to recruit talented minority high school students to science or mathematics teaching, as well as the efforts only resulted in recruiting only on student high school students to undergraduate teacher education program. This results aligns well with the findings of Summerhill, Myrna, Peltier, & Hill (1998).

Our discussion and implications suggest that more strategic efforts are need while recruiting students, especially minorities, at all career levels (direct from high school, transfer from community college, change of major, and career changers). As it was discussed earlier, comprehensive examination of the TSM data from year one to year three indicated that most of the individuals who inquired about the TSM program and recruited to TSM were through personal contacts and efforts. Thus, we would suggest that teacher recruitment programs, especially those that are targeting minorities, to invest their human and financial resources into personal efforts, e.g., advising and promoting the program with the help faculty in undergraduate and graduate programs that are relevant to the focus of the recruitment efforts.

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Appendix A: Open House Questionnaire

Whose opinions do you care about in terms of your choice of career?
When did you first think about becoming a teacher?
Have you had any prior teaching experience such as tutoring, Sunday school, teacher aid, teacher assistant, etc.?
At this point, how committed are you to pursuing a teaching career?
Why are you interested in becoming a math or science teacher?
What aspects of math or science teaching are most attractive to you?
What aspects of math and science teaching are least attractive to you?
What strategies you think could be taken to make the teaching profession more attractive?
Is there anything that would help attract you to a teaching career?

Appendix B: Sample Items from Thoughts about the Teaching Profession Questionnaire

Please note your level of agreement with the following statements about teaching and the teaching profession. Because this measures your opinion, there is no "correct" answer to any of these questions. Circle the number from 1 to 6 that best represents your level of agreement where

1 = no agreement and 6= 100% agreement.

1. I am committed to becoming a teacher

   1 2 3 4 5 6

2. I would like to teach in an urban school.

   1 2 3 4 5 6

3. Teachers have a good deal of job security.

   1 2 3 4 5 6

4. When taking into account salary, benefits, and time off, teachers are well-compensated.

   1 2 3 4 5 6

5. A teacher training program is more important than a natural teaching ability in the development of good teachers.

   1 2 3 4 5 6

6. Why did you decide to consider teaching?

7. Why have you enrolled in this course?

8. If you are not totally committed to a teaching career, please list career possibilities other than teaching that you are considering. For each one, add a number in brackets to indicate the strength of your commitment.

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Appendix C: Sample Semi-Structured Interview Questions

- What can you tell me about your previous work experience? (career changers)
- What teaching experience have you had in teaching science/mathematics prior enrolling in the TSM?
- What factors influenced your decision to enter science or mathematics teaching?
- In your opinion, what are the general factors that (might be) important to you when choosing a career?
- In your opinion, what is science/mathematics teaching entail?
- What did prompt your change from previous employment to begin a career in teaching?
- What role has society played in influencing your decision to pursue a career in teaching?
- What aspects of teaching science or mathematics do you believe make it easier to teach science or mathematics?
- What aspects of teaching science or mathematics do you believe make it harder to teach science or mathematics?
- Thorough your experiences at Exploring class, have you found teaching to be better or worse that than what you have expected?
- As you consider not choosing a career in teaching what aspects or considerations of another job have you considered?
- Could you name any changes that might make you rethink about choosing a career in teaching?

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RESEARCH REPORT

Growth rate in CXC STEM subject entries: Implications for meeting the development needs of the Caribbean

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Abstract: *After years of emphasizing the need to prepare students with skills acquired though the study of science, technology, engineering and mathematics (STEM) for the demands of the job market and to support economic development, there is a need to assess the extent to which subject entries for end of secondary school examinations in the Caribbean reflect change in this direction. Such an assessment was undertaken by examining the extent to which students are taking STEM clusters of subjects in the May/June Caribbean Secondary Education Certificate (CSEC) examinations of the Caribbean Examinations Council (CXC). It was found that the number and percentage of entries for STEM subjects was higher than those for the overall CSEC subject entries. A low rate of positive growth was noted in many clusters of STEM subjects along with periods of negative growth. It was concluded that, at best, the growth rate in STEM subject entries was anaemic. In view of the importance of the STEM subjects in preparing secondary school students both for the world of work and for advanced studies that will provide critical advanced skills required in the work force of the twenty-first century, more effective policy and policy implementation in education must be pursued in the Region to ensure a sharper focus on STEM education at the secondary level.*

Keywords: *STEM education, secondary education, Caribbean Examinations Council, Caribbean development, education policy.*

Background and Purpose

Value of STEM Education

The extent to which the school curriculum is placing emphasis on science, technology, engineering and mathematics (STEM) education is now a fundamental global concern (Donovan, Mateos, Osborne, & Bisaccio, 2014; Merchant, Morimoto, & Khanbilvardi, 2014). This is due to the widely held view that the growth of economies worldwide requires the types of innovation and skills which STEM education provides (Corlu, Capraro, & Capraro, 2014; Kuenzi, 2008; OECD, 2010; UNESCO, 2009). Progress in science, technology, engineering and mathematics is therefore seen as a catalytic force for innovation-driven growth (National Academy of Sciences, National Academy of Engineering & Institute of Medicine, 2011). It is not surprising that in today's world, an increasing number of jobs are requiring STEM-related competencies (Jang, 2016; Lacey & Wright, 2009).

Access to programs of study in STEM-related areas is considered important for the development of skills that are in demand and that will allow individuals to contribute to, and benefit from, the technologically driven economic development programme which characterise nation building in the twenty-first century (Jang, 2016; Padro, 2010; Pawloski, Maas, Meyers, Standridge,

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& Plotkowski, 2010). The focus of the school curriculum on STEM education will prepare students, better, for both direct entry into the world of work and advanced studies that will provide critical skills required in the work force of the twenty-first century. (Beede et al., 2011; Corlu et al., 2014; Evans, McKenna, & Schulte, 2013; Lacey & Wright, 2009). It is therefore not surprising that there is renewed interest in STEM education worldwide. In the United States, this renewed interest might have arisen out of the concern that the results on international tests in science and mathematics, in particular, had ranked that country below a number of its competitors and the implications that this would have for the global competitiveness of the United States (Eberle, 2010; Kuenzi, 2008; Sanders, 2009). This was the concern that prompted the following statement by Arne Duncan, then United States Secretary of Education:

> Everyone has a stake in improving STEM education. Inspiring all our students to be capable in math and science will help them contribute in an increasingly technology-based economy, and will also help America prepare the next generation of STEM professionals-scientists, engineers, architects and technology professionals - to ensure our competiveness. (U.S. Department of Education, 2010)

There is an evident concern in Europe, as well, about the need to expand and improve STEM education to assure competitiveness of the national and regional economies (Kudenko & Gras-Velázquez, 2014; Rohaan, Taconis, & Jochems, 2010). A number of studies show that in Europe, steps are being taken to increase students' interest in STEM studies and careers. These include improved pedagogical approaches to give students a better understanding of the relevance of STEM to life and the world of work, and engaging students in awareness-raising activities around STEM jobs (Joyce, 2014; Kudenko & Gras-Velázquez, 2014; Rohaan et al., 2010).

In the Caribbean, there is also a new interest in STEM education. This is due to a recognition of the need to develop a pool of skills that will facilitate the best use of the Region's comparative advantage, as well as to encourage and support investment that will help to grow the Region's economy out of the debt which constrain development in many Caribbean countries. Warde and Sah (2014), in an article on STEM education considerations in the Caribbean, made the point that STEM education, coupled with entrepreneurial education, is a necessary path for Caribbean countries in order to work their way out of their current indebtedness. STEM education is important to the future economic prosperity of countries in the Region.

However, a World Bank report on the Organization of Eastern Caribbean States (OECS) – a sub-grouping of Caribbean countries – notes that only a few of the less than 15 percent of students who attend post-secondary education in the OECS, enroll "in programs that are considered to be in high demand (i.e. Sciences, Engineering, Mathematics)" (World Bank, 2013, p. 6). According to the report, school leavers in the Caribbean struggle to find formal employment due to a mismatch between the education they receive in the region and the demands of the job market. The report suggested that systemic changes are required in the education provided to students in the Caribbean so that they may acquire skills that would help them to find a place in the job market (World Bank, 2013). This is a clear call for action to reform the education system to focus more on the skills that are required in the job market. These are, essentially, STEM-related skills.

There is an obvious need for more students to pursue STEM-related programmes. This is particularly so for those who are completing their final years of school since most of them will enter the job market with expectations of securing early employment. The lack of appropriate skills may leave many disappointed with the need to retool to acquire competencies which they could have acquired prior to leaving school, had the focus of the curriculum been on STEM-related preparation.

A few countries in the Region have been attempting a more focussed, systemic approach in addressing the issue of better preparation of students with the competencies that are required for the job market. Jamaica provides a good example of such recent efforts. In full recognition of the need to re-focus the curriculum in schools, the Ministry of Education in Jamaica has recently embarked on a programme to infuse a STEM methodology into the curriculum at all levels of its education system and to concentrate on the development of specialized STEM skills for students in their final years of secondary education. According to the Ministry, the plan is to "transform selected High Schools into STEM Academies and to incorporate STEM methodology in all schools" (Ministry of Education, Jamaica n.d., p. 1). The Jamaica Observer newspaper of November 20, 2015, in an article titled STEM curriculum to roll out in schools next year, citing statements from the Ministry of Education, Jamaica, reported that "the incorporation of Science, Technology, Engineering and Mathematics (STEM) methodologies in the curriculum of schools will be rolled out in the 2016 academic year". The newspaper further pointed out that the subjects will be taught to students at the Grades One to Nine levels in primary and secondary institutions and noted that nine High Schools had already been specifically selected to be transformed into STEM academies.

These are recent initiatives whose success will have to be assessed at some future date. A more current concern is the extent to which the importance of the discussions over the last few years about the need for a greater focus in the Region on equipping students with STEM-related skills to meet the demands of the job market and to support economic growth and development is reflected in the programmes being pursued by students. This concern is particularly important for those students who are completing their last years of secondary school since most of them are imminent entrants to the job market.

The issue, therefore, is whether the Caribbean education system has been preparing secondary school graduates to meet the current and future demands for expertise in science, technology, engineering and mathematics. An examination of the extent to which students at the end of secondary school level are pursuing certification in STEM-related subjects would shed light on this matter.

Role of CXC and Reciprocal Responsibility of Territories

The Caribbean Examinations Council (CXC) plays an important role in defining the nature of the education provided to secondary school students in the Caribbean, and in particular those students pursuing secondary school completion for various destinations in employment and further education. These students prepare for, and take a mix of subjects in the Caribbean Secondary Education Certificate (CSEC) Examinations in keeping with their interests.

Article III (a) of the Agreement Establishing the Caribbean Examinations Council (1972) charged the Council with conducting "such examinations as it may think appropriate" and awarding "certificates and diplomas on the results of the examinations so conducted". With this mandate, the Council is expected to play a leading role in assuring an education for students that is fit for the purpose of Caribbean regional development.

Given the importance of STEM subjects in providing the pool of competencies to support regional development, it is reasonable to expect that the offerings of CXC will reflect an emphasis on courses of study and related examinations in science, technology, engineering and mathematics. There is, of course, a corollary obligation, on the part of participating member-territories of CXC to emphasize in their respective schools, the preparation of students in these areas. This should be reflected in larger numbers of entries for clusters of subjects in science, technology, engineering and mathematics among those taken by students.

Purpose of the Study

After years of articulating the importance of preparing Caribbean students with skills that are critical for the job market, including skills acquired through the study of science, technology, engineering and mathematics, it is necessary to assess the extent to which subject entries of students in the end of secondary school examinations reflect progress in this direction. This study sought to assess the extent to which students preparing to exit the secondary education system were taking the STEM-related clusters of subjects in the end of secondary school May/June CSEC examinations of CXC.

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Method and Procedures

Research Questions

The following two related research questions guided this investigation:

1. To what extent does the number and proportion of entries for STEM-related subjects in the CSEC examinations of CXC reflect a positive change in popularity of these subjects among students at the end of secondary school level?
2. To what extent does the growth rate in entries for STEM-related subjects in the CSEC examinations reflect changes that are consistent with increasingly higher value being placed on these subjects by students at the end of secondary school level?

Sampling

The study utilized a purposive total population sampling approach (Emerson et al., 2001; Kyaga, Lichtenstein, Boman, & Landen, 2015; Langstrom, Frisell & Lichtenstein, 2011; Krokstad, Kunst, & Westin, 2002). This type of sampling is not frequently used in educational research where large populations are involved. A representative sample is usually drawn from the population and inferences made to the population based on findings from the sample. In the current study, the data were fully and easily accessible for the total population with the characteristics with which the study was concerned.

Definition of Terms

For this investigation, the STEM-related subjects comprised clusters of subjects which may be classified as science, technology, engineering and mathematics clusters, selected from the full offerings of subjects in the CXC CSEC examinations. In the rest of this article, these will be referred to as STEM subjects or STEM clusters of subjects, as appropriate. The science cluster of subjects comprised the three subjects in the single sciences. These are CSEC Chemistry, CSEC Biology and CSEC Physics. The syllabuses for all three subjects emphasize skills of using scientific concepts and principles to resolve issues. The syllabuses for these subjects aim to develop investigative and problem-solving skills as well as skills of ethical conduct, team work, critical thinking, innovation and effective communication of scientific information (CXC, 2006; 2013a, 2013b). Clearly, these are the type of skills that students who have completed their secondary education would need for the job market.

The technology cluster of subjects in this study comprised offerings in the following five subjects: Building Technology - Construction, Building Technology - Woods, Technical Drawing, Information Technology, and Electronic Document Preparation and Management. The Building Technology – Woods, and Building Technology - Construction syllabuses focus on the acquisition of knowledge, skills and attitudes needed for employment at entry level in the wood and construction industries, respectively. They provide practical experiences that will enable students to develop skills in the use of tools, materials and processes associated with the woods industry (CXC, 2015a). The Technical Drawing syllabus provides foundational skills useful for careers in drafting, architecture, surveying, civil engineering, interior designing, design engineering and the general construction and manufacturing industries (CXC, 2015b). The Information Technology syllabus emphasizes the development of proficiency in the use of productivity tools (CXC, 2008a) while the Electronic Document Preparation and Management syllabus is designed to equip students with knowledge and computer-related skills required to enhance the performance of clerical and administrative tasks (CXC, 2012). These technology subjects will also help students to develop critical job market competencies.

For this investigation, the engineering cluster of subjects comprised two CSEC offerings - Electrical and Electronic Technology, and Mechanical Engineering Technology. These subjects target the acquisition of the knowledge, skills and attitudes needed for employment at the entry level,

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including practical experiences, in fields related to the discipline (CXC, 2015a). The competencies they seek to develop are directly linked to the job market.

For this investigation, the mathematics cluster of subjects comprised CSEC Mathematics and CSEC Additional Mathematics. The Mathematics syllabus seeks to prepare students for the use of specific mathematical techniques in future careers, for example, in agriculture and in commercial and technical fields (CXC, 2008b). The Additional Mathematics syllabus builds on the foundation provided in CSEC Mathematics and emphasizes skills of logical reasoning. Students completing this subject are expected to be in a position to make a smooth transition to higher levels of study in mathematics, or move on to career choices where a deeper knowledge of mathematics is required (CXC, 2010). These two mathematics subjects provide the foundations to do well in a wide range of jobs and in the Caribbean at least one of them is usually required for most entry level jobs sought by secondary school graduates.

Data for the Study

Two sets of data were required for this study. The first set of data comprised the total population of candidates in the 16 CXC member-countries who took the CSEC examinations in the 15 selected STEM clusters of subjects over the nine year period 2006 to 2014. The second set of data comprised the total population of candidates in the 16 CXC member-countries who took all 34 CSEC subject examinations offered over the nine year period 2006 to 2014. The aggregated candidate entries across the 16 CXC member-countries for each of nine years for both the first and second set of data were extracted from a soft copy of CXC's annual Statistical Bulletin for the years 2006 to 2014. These candidate entries formed the primary sources of data for the study.

Procedures

The CXC Statistical Bulletin contains examinations data which the Council provides to its member-countries. It is provided as a soft copy on an external storage device such as a compact disc or a USB flash drive. The data provided includes subject entries and results for the current and past years. Some types of data are provided for a five year period.

The data for the study were drawn from more than one annual Statistical Bulletin and compiled to provide the data required for the study. With the use of EXCEL Pivot Tables, the reports required for the study were generated and exported into Microsoft Word where refinements were made to ensure satisfactory and consistent format of tables and graphs which summarised the findings and enhanced data analysis.

Results

Number and Proportion of CSEC Entries for STEM Subjects

Figure 1 shows a comparison of the absolute number of subject entries for all CSEC subjects for the nine years, 2006 to 2014 and those for the STEM cluster of subjects. It shows that there was an annual increase in overall CSEC subject entries between 2006 and 2012. In 2006, there were 536,910 entries. By 2012 this had increased to 634,678. This represents an increase of 18.21 percent over that period.

In the case of the combined entries for the STEM cluster of subjects, there was a steady increase between 2006 and 2012 - from 174,001 in 2006 to 215,462 in 2012. This represents an increase of 23.83 percent over that period.The figure shows, however, that in the post 2012 period both overall entries and entries for the STEM cluster of subjects declined. Overall subject entries declined from the 634,678 in 2012 to 602,333 in 2014, a decline of 5.10 percent. The decline for the combined STEM entries in the same period was from the 215,462 in 2012 to 212,114 in 2014. This represents a decline of 1.55 percent over that period.

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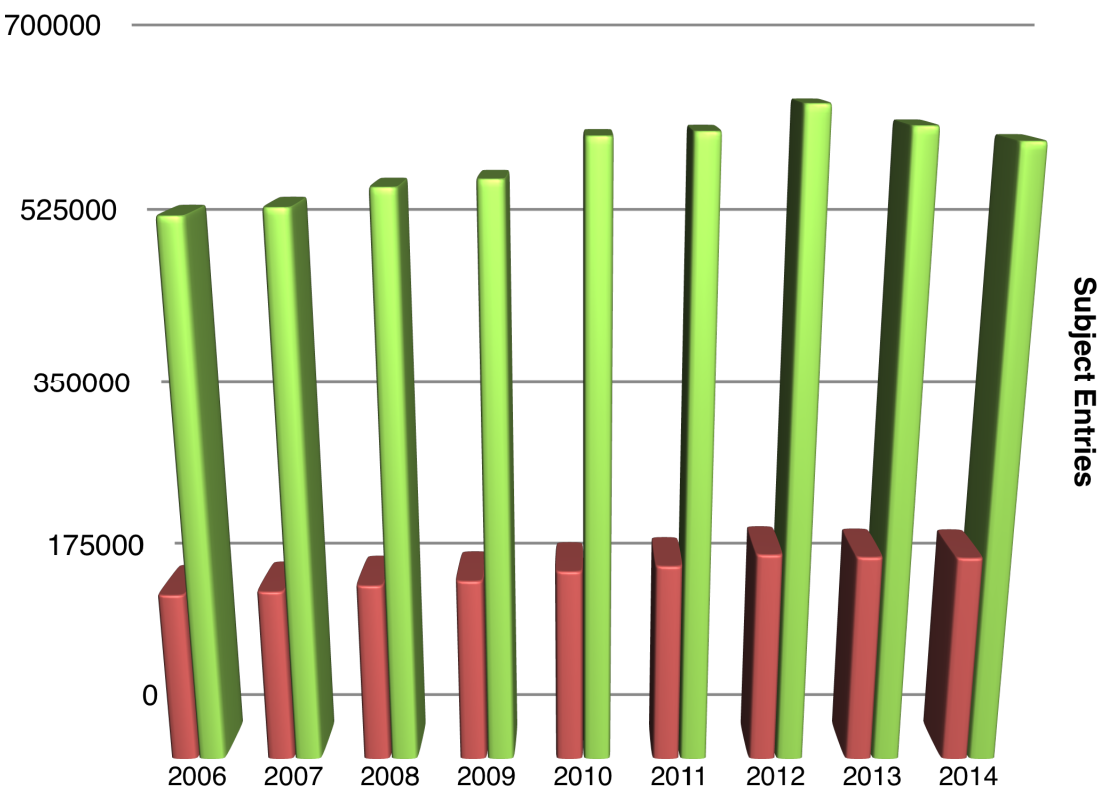

Figure 1. Comparison of overall subject entries and total STEM subject entries for the period 2006 to 2014

Evidently, in the years when there was an increase in both the overall subject entries and the combined entries for the STEM cluster of subjects, the percentage increase in the entries for the STEM cluster of subjects was larger than that of the overall entries. Also, during the period of decline which was shared in common by the overall entries and the entries for the STEM cluster of subjects, the decline was less pronounced for the STEM cluster of subjects than for the subjects overall.

This would suggest that over the nine year period, there was a more favourable increase in the entries for STEM clusters of subjects compared with the overall CSEC entries. However, this seemingly favourable assessment of the STEM cluster of subjects must be tempered by the consistently small proportion of students who took the STEM subjects in each of the nine years. These proportions are reflected in Figure 2.

Figure 2 shows that STEM subject entries as a proportion of overall subject entries for the CSEC examinations ranged from 35.22 percent of the overall entries (in 2014) to 32.41 percent (in 2006). The mean percentage across the nine year period was 33.43. The figure shows that since 2006, there has been a steady annual increase in the proportion of CSEC STEM subject entries. The only exception in the nine year period was a small decrease in 2010 to 32.68 from 33.10 in 2009. This shows that the STEM subjects entries as a percentage of the overall CSEC subject entries had an upward trajectory.

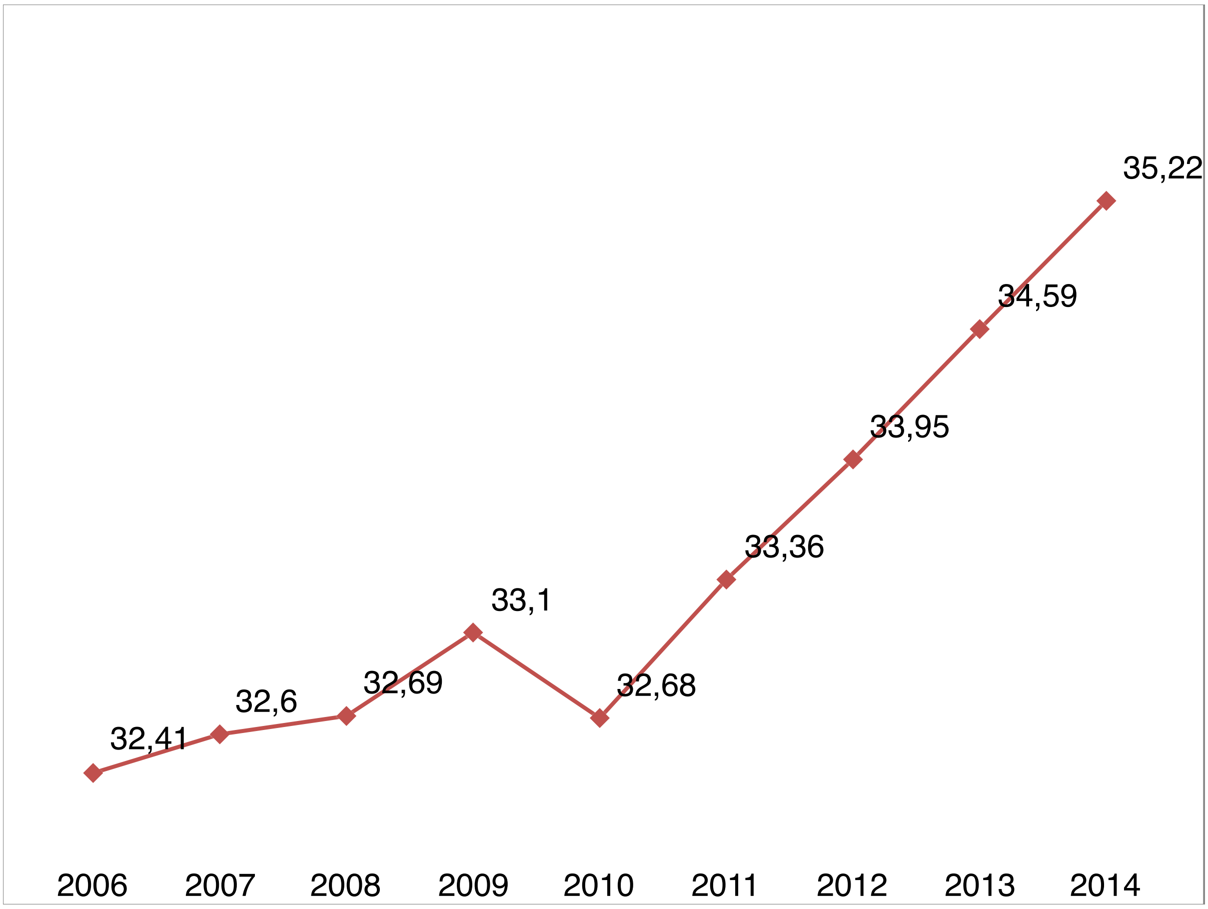

Figure 2. Percentage of STEM subject entries over the nine year period 2006 to 2014

However, it is important to note that over the nine year period, the proportion of increase for the STEM cluster of subjects was no more than 2.81 percentage points – from 32.41 percent in 2006 to 35.22 percent in 2014. Given the importance of STEM subjects in meeting job market needs in the Region and in catalyzing development, such a small increase in the proportion of end of the secondary school population taking STEM subjects cannot be regarded as satisfactory.

Growth Rate in Entries for STEM Subjects

Table 1 shows that growth rate for the overall CSEC entries, that is, for the 34 CSEC subjects, ranged from 6.18 percent (in 2009-2010) to -3.08 percent (in 2012-2013). The mean growth rate for these subjects over the nine year period covered by the study was 1.39 percent. The Table shows that for the 15 STEM subjects, combined, the growth rate ranged from 5.43 percent (in 2011-2012) to -1.38 (in 2012-2013). The mean growth rate for these subjects over the nine year period was 2.40 percent.

For all years except one, the growth rate for the combined STEM subject entries was better than the growth rate for the overall CSEC subject entries. The exception was 2009-2010 when the overall CSEC entries grew by 6.18 percent compared with 4.97 percent for the combined clusters of STEM subjects. It is evident that 2010 was an anomalous year. This was already noted in the previous section when considering the number and proportion of CSEC entries for STEM subjects.

Table 1.
Comparison of the growth rate of STEM subject entries and overall CSEC subject entries for the period 2006-2014

Year	Entries for STEM Subjects					Overall Entries
	Science	Technology	Engineering	Mathematics	Combined	
2006-2007	0.58%	7.35%	5.29%	-0.15%	1.97%	1.38%
2007-2008	0.97%	9.47%	-4.09%	1.80%	3.42%	3.17%
2008-2009	3.67%	6.58%	6.98%	-0.42%	2.50%	1.27%
2009-2010	7.51%	1.18%	4.35%	5.87%	4.97%	6.18%
2010-2011	5.87%	3.84%	-2.83%	0.97%	2.65%	0.65%
2011-2012	7.11%	2.79%	3.54%	6.13%	5.43%	3.75%
2012-2013	1.82%	-1.55%	-1.18%	-2.34%	-1.38%	-3.08%
2013-2014	1.55%	2.78%	-1.76%	-2.97%	-0.40%	-2.22%
Mean Rate	3.64%	4.05%	1.29%	1.11%	2.40%	1.39%

It is evident from Table 1 that of the four clusters of STEM subjects, it was only the science cluster which experienced sustained though uneven growth over the 2006 to 2014 period. There was one year of negative growth for the technology cluster of subjects, that is, in 2012-2013. The engineering and mathematics clusters both showed negative growth in four of the eight periods. These two clusters of subjects shared negative growth for identical periods on two occasions, 2012-2013 and 2013-2014. These were the same years that the combined STEM entries and the overall entries showed negative growth.

Except for the first two years (2006-2007 and 2007-2008) growth in entries for the science cluster of subjects was consistently better than growth in the overall CSEC entries. No similar pattern existed for the other clusters of subjects. In five of the eight years, the technology cluster of subjects showed a growth rate higher than that of the corresponding overall CSEC growth rate. Three of these were in the first three years (2006-2007, 2007-2008 and 2008-2009) while the others were in the last two years (2012-2013 and 2013-2014). For the engineering cluster, there was higher growth rate in four instances than in the corresponding overall CSEC growth rate (2006-2007, 2008-2009, 2012-2013 and 2013-2014). In the case of the mathematics cluster, the growth rate was higher than for the overall CSEC entries in only three corresponding years (2010-2011, 2011-2012 and 2012-2013).

Discussion

The study sought to assess the extent to which students preparing to exit the secondary education system were taking the STEM cluster of CXC subjects. In this study, the science cluster of subjects comprised the three CSEC single-science subjects – Biology, Chemistry and Physics; the technology cluster comprised the CSEC offerings in Building Technology - Construction, Building Technology - Woods, Technical Drawing, Information Technology, and Electronic Document Preparation and Management; the engineering cluster comprised two CSEC offerings - Electrical and Electronic Technology, and Mechanical Engineering Technology; and the mathematics cluster comprised CSEC Mathematics and CSEC Additional Mathematics.

The research used a purposive total population sample. It utilized two sets of data. The first was the total population of candidates in the 16 CXC member-countries who took the 15 selected CSEC STEM subject examinations over the nine year period 2006 to 2014. The second was the total population of candidates who took all 34 CSEC subject examinations offered in the 16 CXC member-countries over the same period.

The first research question was concerned with the extent to which the number and proportion of entries for the CSEC STEM cluster of subjects reflected a positive change in popularity of these subjects among students at the end of secondary school level. It was found that for the first seven

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years covered by the study (2006 to 2012) there was a steady increase in the number of candidates taking STEM subjects. The increase ranged from 174,001 in 2005 to 215,462 in 2012. This provided some evidence of increased popularity of STEM subjects over that period. After 2012, there was a decline in the number of students taking STEM subjects - 212,967 in 2013 and 212,114 in 2014.

A similar pattern of growth and decline was noted for the overall entries in the CSEC examinations. However, the percentage increase in entries in the period of growth was higher for the STEM clusters of subjects than for the overall entries in CSEC subjects. Also, during the period of decline, the decrease in entries for the STEM cluster of subjects was less severe than for the overall CSEC subject entries. For the STEM clusters, there was a 23.83 percent increase in entries between 2006 and 2012, compared with 18.21 percent for the same period for overall CSEC entries. The decline in entries over the period 2012 to 2014 was 1.55 for STEM subjects, compared with 5.10 for the overall CSEC subject entries.

It is likely that the downward trend in numbers for both the overall entries and the STEM entries between 2012 and 2014 was due to the economic challenges which many Caribbean countries experienced from the delayed effects of the widely discussed global recession of 2008 (Mercer-Blackman & Melgarejo, 2013). A recent United Nations report explained the challenge emanating from the global recession for developing countries such as those in the Caribbean. According to the report:

> During 2012, global economic growth has weakened further. A growing number of developed economies have fallen into a double-dip recession. Those in severe sovereign debt distress moved even deeper into recession, caught in the downward spiralling dynamics from high unemployment, weak aggregate demand compounded by fiscal austerity, high public debt burdens, and financial sector fragility. (UN, 2013, p. 1)

This summarises well, the post 2012 circumstance of most Caribbean countries. It is likely that these circumstances affected the capacity of a number of parents to meet the cost of financing their children for the CSEC examinations and is therefore likely to be a significant contributory factor in the decline of the overall entries for CSEC examinations from 2012.

The growth and decline figures for the STEM cluster of subjects and the overall CSEC examinations, taken together, suggest that over the nine year period, there was a more favourable, though small, increase in the entries for the STEM cluster of subjects than in the overall CSEC entries.

Over the nine year period covered by the study, combined STEM subject entries, as a proportion of overall CSEC subject entries, ranged from 32.41 percent in 2006 to 35.22 percent in 2014. In fact, the combined STEM subject entries as a proportion of overall CSEC entries had an upward trajectory across the nine years. The only exception to a steady increase in the proportion of STEM subject entries across years occurred in 2010 when STEM subject entries as a proportion of overall CSEC subject entries declined from 33.10 percent in the previous year to 32.68 percent.

The increasing proportions of STEM subject entries, though a positive finding for the STEM cluster of subjects, must be interpreted with caution. These proportions are not as large as one would reasonably expect if indeed STEM subjects were being given the expected preference as preparation for employment and further studies in relevant high demand areas as advocated by many (Corlu et al., 2014; Lacey & Wright, 2009; Ministry of Education, Jamaica, n.d.; Padro, 2010; UNESCO, 2009; World Bank, 2013).

If students were responding to the espoused importance of STEM subjects in providing education fit for the purpose of educating them for both the existing skill demands in the employment sector and their preparation for advanced studies in high demand areas in the work force, the numbers and proportion pursuing the STEM subjects should have been much larger. One would reasonably expect the entries of the 15 STEM subjects considered in this investigation to represent well over 50 percent of the subject entries for the 34 CSEC subjects.

The second research question was concerned with the extent to which the growth rate in entries for STEM subjects in the CSEC examinations reflect changes that are consistent with

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increasingly higher value being placed on these subjects by students at the end of secondary school level. The nine year period covered by the study allowed for eight periods over which growth rate could be considered.

It was found that for all periods, except one, the growth rate for the combined STEM subject entries was better than the growth rate for overall CSEC entries. The exception was in 2009-2010 when the combined STEM subjects grew by 4.97 percent compared with overall CSEC entries which grew by 6.18 percent. This growth of STEM subject entries at a higher rate than the overall CSEC entries is consistent with what may be reasonably expected, given the importance attached to STEM subjects.

Growth rate for the various clusters of STEM subjects, as well as for the combined STEM clusters fluctuated at a low level over the nine years and no pattern or trend was evident. The growth rate for the technology cluster was positive for seven of the eight periods covered in this study and higher than the growth rate for the CSEC overall entries for six of the eight periods. The mean growth rate of 4.05 percent across the eight periods for this STEM cluster of subjects was, in fact, higher than that of any other cluster. This is noteworthy. This might well be an indication that students at the end of secondary school level are responding positively to the growing demand in the job market for competencies associated with these subjects.

Though the mean growth rate of 3.64 percent for the science cluster of subjects over the eight periods covered by the study was not as high as that for the technology cluster, it was only this cluster that showed sustained positive growth over all eight periods covered by the study. Except for the first two periods (2006-2007 and 2007-2008), growth rate in the Science cluster of subject was consistently better than the growth rate in the overall CSEC subjects entries. There was no parallel finding for any other clusters of subjects.

While the science cluster, like the technology cluster might well be responding to the job market demands, there is at least one other consideration that may be influencing the growth rate of the science cluster of subjects. The science cluster forms a critical offering in the more prestigious secondary schools in the Caribbean. As Griffith (2013a) noted, these are subjects that larger numbers of high performing students are likely to pursue. Because of the accepted value of these subjects, parents are more likely to make the sacrifice in difficult economic circumstances to finance the cost of the examinations in these subjects. This matter was discussed earlier when considering the findings in relation to the first research question.

The growth for mathematics, a gateway cluster not only for other STEM clusters of subjects, but also for several other areas of study, was negative for half of the eight periods covered in the study. The mean growth rate for the periods was merely 1.11 percent which was below the mean growth rate for the overall CSEC entries. Only in three of the eight periods did the growth rate for the mathematics cluster exceed the growth rate for the overall CSEC entries.

The centrality of mathematics in secondary education generally, and in STEM education specifically, would lead to the reasonable expectation that there would be a sustained, and increasing, positive growth rate in this cluster of STEM subjects and that the growth rate would be higher than that of the overall CSEC subject entries. This is a matter of grave concern which needs to be addressed in the Region if the Caribbean is to turn out graduates with the competencies that this cluster of STEM subjects provides and which are important for the development of skills required in a technologically driven economic development programme which is important for nation building in the twenty-first century (Padro, 2010).

Like the mathematics cluster, the growth rate of the engineering cluster of subjects was negative for half of the eight periods covered in the study. The mean growth rate of 1.29 percent for this cluster of subject was only marginally better than that of the mathematics cluster and, like the mathematics cluster, fell below the mean growth rate for the overall CSEC entries. Also, it was only in four of the eight periods that the growth rate for the engineering cluster exceed the growth rate for the overall CSEC subject entries.

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The subjects in the engineering cluster (Electrical and Electronic Technology, and Mechanical Engineering Technology in this study) target the acquisition of the knowledge, skills and attitudes needed for employment at the entry level, including practical experiences, in fields related to the discipline (CXC, 2015a). These are competencies directly linked to the job market and which are essential for the national development programmes of the Region. The slow rate of growth is a matter that requires urgent attention in the Region.

Taking into account the emphasis placed on the STEM subjects to meet the job market demands and to support sustained economic growth in the Region (World Bank, 2013), the rate of growth for the STEM cluster of subjects could not be deemed satisfactory. The growth rate is, at best, anaemic. At the observed average rate of growth of 2.40 percent for the combined STEM cluster of subjects, it would require 30 years to achieve a doubling of entries! This is clearly untenable to meet the development needs of the Region. A doubling of the entries of these subjects over a three to five year period would be a reasonable expectation. That will require a growth rate of 24.0 to 14.4 percent.

Ritz and Fan (2015) pointed to the fact that, in many countries, although there have been continued discussions about STEM education, little action has been taken to modify educational systems to deliver this form of education. This appears to be true of the Caribbean. There is an evident need for a more effective policy on STEM education in the Region.

Conclusion and Recommendations

There can be no denying that STEM education is important for the preparation of secondary school students both for the world of work and for advanced studies that will provide critical advanced skills required in the work force of the twenty-first century. (Corlu et al., 2014; Lacey & Wright, 2009). More must be done in the Caribbean to reflect an awareness of this reality.

More effective policy and policy implementation in education must be pursued in the Region to ensure a sharper focus on STEM education at the secondary level. Policy implementation would need to be buttressed by a dynamic public education programme. In this regard, the following views expressed by one Caribbean author are worthy of consideration:

Despite years of educational reforms and redirection of educational investment to generate secondary school graduates to meet our development needs, the performance of students, teachers and schools still seems to be judged by performance in subjects associated with the ancient grammar school education. Perhaps, this is a case of repetition conquering reason. Those who have been castigating students, teachers and schools have been so vociferous that they seem to have shouted down the reformers, and even those in the employment sector now seem to have forgotten what they really need. They too, seem to have joined the chorus in calling for success in the traditional grammar school subjects for entry level employment. We seem to have lost our way. (Griffith, 2013b, p. 28)

A more positive response to the STEM initiatives in the Caribbean, and improvement in the popularity of STEM clusters of subjects in the CXC examinations, will require extensive public education to help parents, teachers, students and employers to appreciate the value of STEM education for employment of secondary school graduates and for the economic advancement of countries in the Region. It will require, as well, an appropriate shift in educational policy by many Caribbean countries to improve the number and proportion of secondary school students who graduate with STEM subjects.

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RESEARCH REPORT

Preschool Teachers' Role in Establishing Joint Action During Children's Free Inquiry in STEM

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Abstract: *With science and digitalization emphasized further in the new Swedish preschool curriculum, there is a need to clarify teachers' role in educating children in and about these areas. In the present study, the Joint Action Theory of Didactics has been used to analyze the didactic game taking place between teachers and children in two preschools during inquiry-based STEM activities, with and without the use of robots during programming. The results highlight different coaching strategies used by the teachers and how these strategies promote the joint actions during children's STEM inquiry integrating programming and science. Interestingly, the joint action-strategies used by the teachers are similar and independent of whether the programming involves digital tools or not. Such strategies involve establishing a common ground of knowledge in the group and hands-on teaching. Both teachers start with teacher-scaffolded activities that develop into free inquiry and exploration through the children's own ideas, coached by the teachers on both individual and collaborative levels. The findings add to the discussion about how teachers can coach preschool children's learning and inquiry of programming and STEM – implications for preschool practice are discussed.*

Keywords: *Preschool, STEM, joint action theory of didactics, programming*

Introduction

During the years, the pedagogical task for Swedish preschool has gradually been reinforced and the national curriculum in 1998 introduced different goals to strive for and content areas to cover (Swedish National Agency for Education, 1998). One of these areas was science and in addition to defining this discipline from the, in preschool context, historical perspective of nature and outdoor experiences, the definition was during revisions of the curriculum broadened to include simple chemical processes and physical phenomena (Swedish National Agency for Education, 2010). Furthermore, from July 2019 a new preschool curriculum is implemented and this time with a strengthened focus on digitalization (Swedish National Agency for Education, 2018). This has resulted in questions being actualized about different didactic aspects such as what content, what methods, when to start and how to take children's perspectives into account, for both science and digital technology. As far as we know, there is no consensus among researchers or educators about how science, technology, engineering and mathematics (STEM) could be identified in a preschool perspective. The aim of this article is therefore to provide novel insight and knowledge of STEM activities integrating science and digitalization in a preschool setting.

Traditional school teaching has treated science, mathematics and technology as separate disciplines but an approach known as integrated STEM advocates for the introduction of these disciplines in an integrated modality since early age (Honey, Pearson & Schweingruber, 2014),

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which fits well with traditions in early-years teaching. The idea of STEM education is to view these disciplines as an entity, the teaching of which is integrated and coordinated as they are applied to problem-solving in the real world (Sanders, 2009). An effective STEM education has to consider children's interest and experience and promote rich and exciting experiences related to the four letters of/in the acronym (Toma & Greca, 2018). It also benefits from encompassing both domains of science discussed by Eshach (2006) in terms of content (concepts, theories, theoretical models) and investigations (hypotheses, problematizing, questions, experiments). In addition, robots are finding their way into classrooms and educational robotics is discussed as a transformational tool for learning computational thinking, coding, and engineering. Educational robotics has been described as an effective learning tool for project-based learning where STEM, coding, computer thinking, and engineering skills can be integrated (Eguchi & Uribe, 2017; Komis, Romero, & Misirli, 2016). In an extended overview of the field Bers (2018) discusses how coding engages children as producers and not merely consumers of technology, and that coding enables new ways of thinking, communicating and expressing of ideas. While the idea of integration when teaching subjects in school is rather new, interdisciplinary teaching is tradition in Swedish preschool. The different areas of the curriculum, such as language, aesthetics etc. are most often integrated and worked with in themes that last for an extended period. However, the handling of the content areas science, technology and mathematic stands out. A recent report by Swedish Schools Inspectorate (2018) describes how preschool teachers often experience an insecurity about work in the three fields, especially in technology, resulting in that work encompassing these goals in the curriculum is avoided in many preschools. We have previously reported on the insecurity experienced by preschool teachers when working with integration of science and digitalization (Authors, 2018a). This insecurity leads to many children being left out of the opportunity to develop further insight of the surrounding world here and now and interest for science and technology, which in turn may affect children's choice of studies later. It is therefore of utmost importance that knowledge is developed of how preschool teachers could implement teaching in these areas (Swedish Schools Inspectorate, 2018).

Joint Action Theory of Didactics

The analysis of this study was based on the Joint Action Theory in Didactics (JATD). Blumer (2004) argued that describing a social act equals describing a

> Joint activity, inside which the individual act is being formed as it is directed to fit into an ongoing patterning of the acts of others (pp. 32–33).

Sensevy et al. (2015) describe the teaching-learning process as a didactic game and a system, comprised of the teacher, the student, and the knowledge to be taught and learned. This system is inseparable and must be viewed as a whole, meaning that one cannot understand the teacher's behavior without at the same time understanding the student's behavior as well as the knowledge structure and function. The didactic game is thus a 'reciprocal game' between the teacher and student in which one player (the teacher) only wins if the other player (the student) wins, that is, learns. The teacher's task is to help the student in the game but in the end the student is the one who must make the 'winning moves', that is, conquer the new knowledge. The term knowledge in JATD is seen as a power of acting in a specific situation, referring to that when you know something, you become able to do something that you were unable to do before, in a specific situation (Sensevy, 2012).

The JATD puts forward three didactic concepts: joint attention (Bruner, 1977; Eilan et al., 2005), joint affordance (Gibson, 1979) and common ground (Clark, 1996). Sharing attention, that is, having a 'joint attention', on the same objects is crucial for a joint action. 'Joint affordance' refers to participants in the same joint action recognizing the same affordances in a given environment (Gibson, 1979) and the concept of 'common ground' (Clark, 1996) denotes the shared preconceptions and understanding of a common background in the situation, enabling communication between participants in joint actions (Sensevy et al., 2015). The didactic process may also be described through a contract-milieu dialectics, where the contract refers to the already established knowledge

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and the milieu to the new knowledge to be conquered through the didactic game. The contract and the milieu in a situation can be considered as complementary entities since new knowledge always refers to, and builds on, older knowledge and what is known from before (Sensevy et al., 2015).

Previous studies where the JATD have been used as an analytical tool have often focused older students and their teachers, working with technology (Svensson & Johansen, 2019), physics (Venturini & Amade-Escot, 2015) and biology and English (Gruson & Marlot, 2016). An exception to this is the article by Sensevy et al. (2015) that reports on JATD-analysis of two cases, one of which is from kindergarten. We see the JATD framework as suitable also for younger children where signs of e.g. attention could be interpreted from physical gestures, a complement if their verbal language is not as developed. The present study therefore extends earlier research with its aim to, via the JATD framework, analyze the didactic game taking place between teachers and children in two different preschools during their inquiry of programming in integrated STEM activities, with and without digital tools. More specifically, the research question guiding the analysis is:

- How are preschool teachers promoting the didactic game with children during inquiry in STEM, with and without digital tools?

Methods

The study originates from botSTEM, an ERASMUS+ KA201 project with partners in Spain, Sweden, Italy and Cyprus. One aim of botSTEM is to develop a research- and evidence-based toolkit, useful for teachers aiming to introduce integrated STEM approaches through collaborative inquiry teaching scaffolded by robotics for four-eight year old students (Greca Dufranc et al., 2020). An on-line toolkit with STEM practices has been developed and more information about the project can be found at botSTEM.eu. A part of the botSTEM project is to implement and evaluate activities from the toolkit and part of that is done by researchers and teachers in Sweden. Three researchers and ten preschools are involved in this process. Participating preschool teachers were part of different competence development courses in science, held by the authors, where they were introduced to the botSTEM project. Ten in-service teachers from the courses volunteered to join and in the present study, two of these preschool teachers, henceforth called Jannica and Caroline, were asked to try out and evaluate an optional botSTEM activity. During an introductory meeting attended by one of the researchers together with Jannica and Caroline, the toolkit was introduced and the methodology explained. Jannica chose the activity called 'Using the Blue-Bot as a link between different aspects of a natural science phenomenon'. The Blue-Bot® is popular in Swedish preschools for work with programming and digitalization. The transparent, beetle-like robot has a bluetooth function, but the Blue-Bot® can also be programmed physically through a set of buttons on its back. It can be programmed to take steps forward, backward, make 90 degree turns, and sequences can be repeated. In the chosen botSTEM activity, children's previous knowledge and experience of a science phenomenon could be coupled to programming through pictures of different aspects of the phenomenon placed on the floor. The children are supposed to program Blue-Bots® to go between two specific pictures. The teacher may e.g. ask the children to program the Blue-Bot® to find the correct animal food source picture among several pictures on the floor, or to go to the picture representing a tulip, among several flower pictures. In the present study, Jannica chose to develop the activity and make a new version of it, as explained further in the Results section. Caroline decided to try the botSTEM activity 'Children programming each other as Blue-Bots'. In this activity, three children work together with assigned roles as 'Blue-Bot®', 'programmer' and 'observer', respectively. On the floor are pictures of arrows in a winding path. For the 'Blue-Bot®' to follow the path, the 'programmer' programs him or her on the back in a manner resembling the buttons on the real Blue-Bot®. A press in the neck means 'forward', a press to the left of the back means 'turn left', a press on the lower part of the back means 'back', etc. Both Jannica and Caroline chose to develop their activities and make new versions of them, as explained further in the Results section.

Jannica, with 26 years of experience from work in preschool and with prior knowledge of the Blue-Bot®, chose four children, two girls and two boys aged five, to participate. Caroline has worked as a preschool teacher for 20 years but had no previous knowledge of the Blue-Bot® or programming, and in her activity, six children, four girls and two boys aged five, participated. Before the activities, the researcher asked for the children's permission to video record their activity. The activities lasted for 27 and 30 minutes respectively, and the whole activities were video recorded and analyzed. Throughout the activities, the teachers and children worked focused and the only exception from this was found in Caroline's activity, where the recording was paused for a short time when one of the children fell and started crying. When the activity started again, so did the recording. In a first step of analysis, the whole videos were transcribed, including description of gestures. In a second step, the transcripts were analyzed according to the JATD framework by both researchers for situations where establishment of joint attention, joint affordance or common ground could be inferred, either verbally or with bodily expressions, among the teachers and children. This was performed through double coding of the selected parts of the transcripts and final coding agreed upon by the researchers in relation to the JATD framework. In a third step, the selected situations were analyzed for patterns of didactic approaches. The didactic approaches represented teaching situations where the teacher successfully enabled establishment of a joint attention, joint affordance, or common ground, evident from the children's responses, either verbally or through actions and gestures. Five categories of didactic approaches were identified: Establishing a common ground, creating interest for the inquiry, hands-on teaching and learning, expanding the learning environment for the individual child and promoting collaborative inquiry through the children's own interest. Excerpts representing the five categories were chosen to exemplify the establishment of joint attention, joint affordance and common ground.

The research adheres to the ethical guidelines of the Swedish Research Council (2018). All participants and children's caregivers are informed and have agreed to voluntary and anonymous participation with a right to abandon participation. Written consent was collected from the parents to all involved children and the children themselves were always given the opportunity to withdraw and not continue to take part in the project. Pseudonyms are used in analysis and reports (see also, Farrell 2016, for a more in-depth discussion).

Results

In preschool 1, Jannica lets all children take part of her activities in small groups and she therefore repeats the activities on several occasions until all children have participated. The children that participated in this study were not especially chosen, but the only ones that had not yet tried out the activity. Jannica and the children start the activity on the floor with an activity involving one Blue-Bot® on a mat with a grid, the mat resembling a small town, see Figure 1. Some squares on the mat constitute streets and others shops. Since before, and therefore part of the common ground and the established contract in the group, the teacher and children have experienced programming the Blue-Bot® via the different buttons on its back. Also, they have for some months worked with the science content rocks and stones, hence the content is already experienced and part of the participants' common ground. In the activity that will follow (the didactic milieu), Jannica creates a didactic game that involves the children, one at a time, programming the Blue-Bot® to go from an optional start-square on the mat to an end-square, where another child has chosen to place the treasure stone. The child has to visualize how the Blue-Bot® needs to be programmed to reach the stone from the start-square and thereafter execute the programming on the robot. When all children have finalized, or tried, the programming, the second part of the activity starts with the children picking one Blue-Bot® each and creating an optional course for their Blue-Bot®. For this they choose freely between any available material in the room, such as KAPLA®-planks (Figure 1), blocks etc., for the Blue-Bot® to navigate in order to find stones that each child has placed somewhere on his or her course. The children are free to choose the arrangement themselves, also if they want to work alone or together with a peer. Two of the children chose to work alone, although, and as we will see, they later teamed up in a common activity, while two of the children worked in a dyad from the start. The children's inquiry took place on the floor with Jannica placing herself in the middle of them, so that she had an

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overview of the situation and could coach them when she found it suitable.

The common ground in preschool 2, and didactic contract, among Caroline and the children in her activity differs from the situation described above. While Jannica and 'her' children have previously worked with Blue-Bots®, the children in Caroline's activity have no previous experience of them. Instead, they have on a previous occasion discussed robots, what they are and where they can be found, and what the word 'instruction' means. This prior discussion was also the inclusion criteria for Charlotte when choosing children for the present activity. Thereafter, they programmed each other two and two by telling verbally what the other should do, for instance jump, dance, etc. In the present activity, Caroline sets up a didactic game and milieu around a group activity where the children for the first time walk a path as shown by arrows on papers placed on the floor. In the original botSTEM activity, only arrows were used as instructions, but on some of the papers, Caroline has added short instructions such as 'take two steps forward' and she helps the children by reading the instructions out loud to them (Figure 2). After having let each of the children try out the path, thereby enabling joint affordance among the children for what the arrows and instructions mean, Caroline expands the didactic milieu by opening up for free inquiry and for the children's own ideas of how to create paths of arrows and instructions.

Below follow excerpts from the activities, exemplifying the dynamics and aspects of the didactic game in progress between the teachers and the children. In focus are the different ways the teachers coach the children in a holding-back manner in creating a learning milieu through establishing a common ground and joint attention and through enabling joint affordances, during the inquiry.

Figure 1. Blue-Bots® in a KAPLA®-plank course on the mat.

Figure 2. The 'arrow path' with instructions.

Didactic approach: Establishing a common ground

Both teachers start their activities by asking the children what they remember from previous activities, thus establishing the common ground and didactic contract in their respective learning situation. The children and Jannica are sitting on the floor around the mat and the teacher initiates the activity by asking the children what they remember about the Blue-Bot® and programming it:

Jannica	Do you remember what the different buttons meant? [She has picked up a Blue-Bot® and holds it in front of her so the children can see it.]
Mimmi	[Throwing herself forward to show with her finger on the buttons on the Blue-Bot®] Yes! There you press forward, there you press … [Hesitates for a second and Anton continues.]
Anton	Ehm, to the right!
Jannica	Schhh [To Anton, in order for one child talking at a time.]
Mimmi	… turn, there you press you should go backwards, there you press you should start, there you press when it should … do it again.
Jannica	When you should do it again, yes.
Mimmi	[Excited] Yes, and…
Jannica	… and then you can program once again. [Spins her hand in the air.]
Stella	I know what that one means. [Points to one of the buttons.]

Jannica only needs to start the activity with the question about what the children remember about the different buttons, and a joint attention is immediately established. All children pay attention to the discussion and when they, like Mimmi in the above example, recapitulate their previous common experience and hence their common ground, they show vividly with their body language and verbally how the Blue-Bot® can be programmed. However, it is not yet clear if also joint affordance is established for the children.

Caroline starts her activity by asking the children what they remember from the previous discussion about programming and robots:

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Caroline	And then we got into what a robot is. What is a robot?
Alice	Kind of a robotic lawn mower.
Elias	Yes, we should program the last time here there was a person you should say what it should do. Program and stuff.
Caroline	Yes, we programmed ourselves /…/ because you told me before what a robot can do. What could it do?
Alice	I know! It could cut grass.
Elias	Yes, I think one could build humans like robots on minecraft.
Caroline	Yes, and I think you were the one that said that you can explore planets and shoot them into space?
Elias	Mm
Caroline	Yes. And then you got the question if they can do these things themselves. Can a robot do it itself?
Alice	Yes, one could program.
Caroline	One could program them. And who is doing the programming?
Alice	Humans!
Elias	The humans who make them.

Through this initial discussion of robots and programming, and through Caroline's questions, she and the children establish the contract and common ground before moving into the new activity and learning milieu.

Didactic approach: Creating interest for the inquiry

After establishing what the group of children already knows and remember about programming the Blue-Bots®, Jannica introduces today's activity:

Jannica	[To Stella] Should you start? [Gives the Blue-Bot® to Stella]. I'll give you an assignment. I'll start by choosing a stone that you will go to. [Opens a plastic box and picks out one of the stones and says with a little exciting voice:] And then I'm gonna choose this one… [Inaudible]-stone. The treasure stone. [Shows the children the stone]
Stella	Wow…

In the situation, all children are following Jannica's framing of the didactic game with interest. She makes the activity exciting by giving Stella 'an assignment' and by using an exciting voice when she introduces the treasure stone. We interpret the word assignment and the exciting voice as didactic factors influencing the milieu and the joint attention in the situation. Another factor that promotes the joint attention for the children in the programming game, is Jannica's choice to let one child program and another child place the stone on a square. She thereby creates a situation where the children have more than one role, either as a programmer or as a 'stone placer' and in both roles the children's perspective is included. They get to choose themselves in what square to put the stone, and in what way to program the robot, respectively. Also, importantly, the Blue-Bot® itself functions as a motivation factor throughout the activity, helping to establish a joint attention. It is obvious from the children's reactions and excitement, physically and verbally, when it is introduced that they look forward to the activity and what will happen.

In Caroline's activity with the 'arrow path', she has included a question mark as one of the instructions. When a child reaches this, s/he get to choose for him- or herself what programming this should mean. This creates an interest and joy among the children, who e.g. jump, turn somersaults and cartwheels as response to the question mark. We see this inclusion of children's own ideas as a decisive step, and their joy of the chosen physical exercises, as a joint attention- and joint affordance-

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enabling factor in the activity.

In all, the robots, the 'assignment', Jannica's exciting voice, children's different roles on the Blue-Bot® mat, and the question mark allowing children to decide their own program steps on the arrow path, create an interest and a joint attention among the children participating in the milieus and didactic games.

Didactic approach: Hands-on teaching and learning

Striking from the data material is the amount of practical and hands-on clarification that goes on between the teachers and children, and between children, in the situations. Throughout the activity, Jannica in preschool 1 shows concretely with her hands what she refers to, thereby sustaining the joint attention and joint affordances in the coached open inquiry:

Jannica	Let's see if we can help each other out, here? [Estimates with her index finger on the mat the distance/squares the robot have to go.] One…
Stella	[Programs the robot]
Jannica	Two …
Stella	[Programs this step]
Jannica	Three …
Stella	[Programs]
Jannica	Do you need to turn? [Points first to the Fish-store that are placed one square to the left, and then to the square where Stella's robot will be on the street, to indicate the turn the robot needs to do.]
Jannica	Will you turn on that square? [Turns with the finger on the square]
Stella	[Programs the robot]

This kind of concrete presentation is constant during the activity. Both children and Jannica point and estimate with their hands during the discussions, enabling a mutual understanding of the situation and thereby sustaining the joint affordances they have the possibility to experience in the inquiry. Some children estimate with their hands how many squares the Blue-Bot® has to go while others only estimate with their eyes on the mat. The next example is from the second phase of the inquiry, where the children are free to choose arrangement around the optional course. Jannica shows Anton how he can build a course with KAPLA®-planks:

Jannica	If you take a kapla-plank, it's approximately the same size as the Blue-Bot® . [Illustrates by putting the kapla-plank and the Blue-Bot® next to each other on the floor.]
Jannica	Then you can build a path yourself if you want to. [Demonstrates by placing some kapla-planks in a row and on both sides of the robot so it stands in a small passage. Anton stands in front of the teacher and watches with interest.]
Jannica	Then you can put a treasure stone somewhere… [Mimmi reaches for the robot but the preschool teacher puts her hand over Mimmi's hand and the robot.]
Jannica	I'm just going to see if it works [she switches on the robot]. If it's as long as a kapla-plank. With a small space there [Adjusts the kapla-planks] I think it will walk one step per one kapla-plank. [Starts the robot and it walks exactly one step on the length of a kapla-plank.]
Jannica	[Looks at Anton] Did you see? So then you can calculate the course with kapla-planks.

After Caroline and the children in preschool 2 have walked and followed the instructions in the arrow path, the didactic game continues with the children re-building the path according to their

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own ideas. In the process, two girls walk the path they have created by walking from one paper to the next but ignoring the instructions on the way. Caroline therefore directs their attention to the instructions by joining in the walk, to physically show what happens if one follows the instructions that after the re-building ended up in an illogical order:

Caroline	Now I think I'm gonna try and walk.
Agnes	You start there. [Points to the paper with the arrow that the girls have chosen as starting point for their path.]
Caroline	You start here? [Stands on the start arrow and begins to read:]
Caroline	'Take one step back' [Takes one step back and ends up in another part of the path where Felicia already stands.]
Caroline	Then maybe I end up here? [The girls laugh.]
Felicia	That won't work!
Caroline	If I take one step back. Then I have to turn. [Turns around and faces the path.]
Caroline	Then it says 'Take three steps forward'
Felicia	Yes
Caroline	[Takes three steps forward but in doing so she walks the path in the wrong direction in relation to the arrows.] /…/ Do you see, Felicia and Agnes? What happened now? If I was here [Goes back to the start arrow], took one step back [Does so], then it says 'Take three steps forward'… [Takes the steps and ends up opposite Felicia who walks the path in the opposite direction. They are in each other's way.]
Felicia	[Laugs] But then I can't..! It won't work!

By showing hands-on and physically, the teachers and children make sure they understand each other's thoughts and intentions and we interpret this concrete teaching and learning as an important aspect of the milieu and didactic game.

Didactic approach: Expanding the learning environment for the individual child

In the didactic game, Jannica uses different strategies to support the individual children's free inquiry and the affordances the child may experience in the situation. One such strategy is to expand the children's use of scientific language. When a child mentions any of the different stones in the activity, Jannica answers by using the stones correct scientific name. An example of this can be seen when the teacher and two of the children are looking in the plastic box containing the stones:

Stella	These should be together all these [Refers to stones in her hand].
Jannica	Was that rose quartz then?
Stella	Mm. Rose quartz.
Linus	I'm gonna have this black stone.
Jannica	Mm, where did you find it? Was it black tonalite?

The teachers also use productive questions that expand the affordances in the children's inquiry, such as in the next example where Stella intends to program the robot to go into the Fish shop on the mat:

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Jannica	Should you try again? Reset again [Stella resets the robot]. What do you need to think about now? You need to go..?
Stella	[Crawls forward on the mat and shows with her index-finger which way she wants the robot to take, across the street and into the fish shop.]

The teachers also widen the children's possibility to learn by directing their attention towards new aspects and affordances of the inquiry they are conducting. During the free inquiry part of Jannica's activity in preschool 1, Mimmi and Stella is creating a competition for their Blue-Bots® to raise down an inclined plane (described below). Mimmi's suggestion is for the robots to raise upwards but Stella insists on downwards and the girls come to agree on that. Jannica notices the discussion and later, when Mimmi is using the inclined plane by herself, the teacher sees the opportunity to coach Mimmi back to her original thought (Figure. 3):

Mimmi	[Starts her robot. It goes downwards and stops at the end of the inclined plane.]
Jannica	Oh. But if you go upwards Mimmi, then what happens? Can it go upwards?
Stella	Yes! I know, 'cause..! [Starts to play claves with two kapla-planks.]
Mimmi	[Puts the Blue-Bot® so it will go up the plane, resets it and starts programming.]
Mimmi	… two, three, four. [The robot is started but immediately slips and ends up askew.
Mimmi	Eh! [Lifts the robot a little bit further up the plane and now it starts going straight up.]
Jannica	It was only in the beginning it needed help. [Soon after, the robot stops when it reaches the top of the plane. Mimmi applauds.]
Jannica	Good!
Mimmi	Wait … [Lifts the plane from the box its leaned against and leans it more steep against the box.]
Jannica	Are you going to try to have it even higher?
Mimmi	[Puts the Blue-Bot® against the now very steep plane, holds it in her hand and tries out the inclination. The plane falls over.]
Jannica	Do you think it can go upwards this slope?
Mimmi	Yes
	[Puts the Blue-Bot® at the end of the plane, facing upwards.]
Jannica	Maybe it needs help in the beginning.
Mimmi	[Programs the Blue-Bot® about five centimetre up the plane and Stella follows with interest.]
Mimmi	Reset! One, two, three, four, five.
Jannica	And go!
Mimmi	[When Mimmi is ready she lets go of the Blue-Bot® that slowly starts to slide backwards on the steep plane. She holds with both her hands around the robot while it slides, ready to capture it if needed. She takes the robot and lifts it higher up the plane to see if it goes better there but it slides backwards also from here. Mimmi takes it and laughs fondly.]
Jannica	[Laughs] Was it that steep? Okey. Can we find something in between here then, with the boxes? He managed that one [Holds with one hand on the lower box]. And that one was too steep [Holds on the higher box]. What could we have that's in between, Mimmi?

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Figure 3. Mimmi programs her Blue-Bot® to go down an inclined plane.

The above excerpt illustrates how the teacher pays attention to the affordances Mimmi sees in her inquiry when she is curious about the robot going upwards and on different inclinations. Jannica detects Mimmi's intentions and aids in her problem solving by offering another box and by asking questions such as "Can we find something in between here then, for the boxes ?", referring to finding a box that will give the plane an inclination that is "not too steep but not too easy either". Thereby, she enables a situation of joint attention and joint affordances between herself and Mimmi around the robot and the inclined plane.

A little bit later Mimmi has stopped exploring the inclined plane and instead starts to program the robot to enter a farmhouse standing on the floor. She estimates how many steps the robot needs to go to enter through the opening in the house and programs the robot accordingly. She tries to get the teacher's attention in doing so but fails since Jannica is involved in talking to another child. After the conversation the teacher turns to Mimmi and watches her program the robot, which then enters the farmhouse and stops as planned. Jannica missed how Mimmi estimated the distance with her hand and sees the opportunity to challenge Mimmi from a meta-perspective, by asking Mimmi to explain her reasoning behind the programming:

Jannica	[Puts her hand om Mimmi's arm.] But Mimmi, how could you know how many steps it should go? There are no tracks… [Shows with her finger on the farmhouse floor where the Blue-Bot® just went.]
Mimmi	'Cause I counted.
Jannica	How did you count?
Mimmi	One, two, three. [Shows with her hand on the farmhouse floor.]
Jannica	But there are no marks that one can follow like in the map over there? [Points to the mat with the grid] Did you just think [Points to her head] that it was approximately this long when it went, or?
Mimmi	[Nods]
Jannica	You could think that in your head?
Stella	[Loudly to the teacher] Do you know that..!
Jannica	You'll have to wait Stella, I'm talking to Mimmi now. How could you know how many steps it should take?

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Mimmi	'Cause it… [Shows the teacher and speaks inaudible.]
Jannica	You counted and thought in the head?
Mimmi	[Nods]
Jannica	Smart!

The teacher's approach to ask the children about their intentions and thoughts during their free inquiry so that she can follow them creates means for joint attention and joint affordances between the teacher and the children. In the next example, Anton has put his robot on the lid on a box and built a tower of small wooden blocks below the box. He programs the Blue-Bot® to go off the edge on the box, falling towards the tower:

Jannica	[To Anton] What's happening here, what is it that you do?
Mimmi	[Sees that the robot is about to go off the box and puts her hands around it to capture it. With her arm-movement she accidently tips over some of the blocks of the tower.]
Anton	No! [The Blue-Bot® goes off the edge and falls to the floor, through the tower that falls down.]
Jannica	Wow. But I'm not sure the robot can withstand it so it was quite smart of Mimmi to try and catch it, actually. I don't know how much they can withstand. But what did you think when you did it?
Anton	That it should go downwards.
Jannica	And tip the tower over?
Anton	No, I mean that it went like this and then brsch… [Shows on the edge of the box how he meant for the Blue-Bot® to go down the tower.]
Jannica	Aha, that it should come down on the tower and then come down?
Anton	Yes
Jannica	Aha, like a stair, or?
Anton	Mm
Jannica	How could it do that [Inaudible]. We need to ponder over that one. Maybe we can use larger blocks? Try them? [Takes out a box with soft, large blocks.]

What at first seems like a somewhat careless handling of the Blue-Bot® and a ruining of a tower is actually part of a more serious inquiry. It appears that what the teacher interprets as a tower of blocks is for Anton some sort of 'staircase' to help the Blue-Bot® downwards towards the floor. The intention is not for the tower to fall. Jannica's choice to ask Anton "But what did you think when you did it?" allows for her and Anton to stay on the same track in the inquiry. By clarifying Anton's intention, she creates means for joint affordance between the two of them in experimenting how they could build a sturdier staircase for the Blue-Bot® to go down by. Anton and the teacher continue the activity by building the stairs with larger blocks, discussing and trying the feasibility of the arrangement.

Didactic approach: Promoting a collaborative inquiry through the children's own ideas

In the data material, several examples of the children's agency and ownership of their inquiry are visible. The following excerpt exemplifies the joint affordances Anton and Linus experience during the second part of Jannica's inquiry activity, where the children arrange their own courses for the Blue-Bots®:

	[Anton and Linus sit by the mat with a box of kapla-planks between them. Linus holds a Blue-Bot® and watches while Anton starts to build with kapla-planks along the grid/street so that two kapla-planks flank one square and a path is created between the kapla-planks.]
Jannica	Do you want kapla-planks in the [Inaudible]-course? [To Anton who does not answer] Or do you want to build it outside on the floor?
Linus	[To Anton] I'm actually gonna drive this way.

	[Puts the Blue-Bot® on the mat so that the robot will cross the path Anton is building on.]
Anton	Aha! Then we can do like this.
	[Puts a kapla-plank so that the path folds in 90 degrees in the direction Linus intended.]
Linus	Okey, then I can drive and break your building here [You can tell from his face that he is joking and both boys laugh]. Shall we both make the path?
Anton	Yes
Linus	Shall we make a path over all of this, over the whole road?!
Anton	Yes we can! If anyone wants to drive there, then there's just a path!

Soon after they are inspired by the preschool teacher who says to Mimmi:

Jannica	Are you gonna try to build a bridge, Mimmi? [Mimmi has started to build a bridge with kapla-planks]
Anton	A bridge yes! Don't you think we should do that Linus?
Linus	Yeees! A bridge here.

In the excerpt, joint affordances between the children are detected when Anton and Linus choose to build their course, or path, together. Anton swiftly changes his course of KAPLA®-planks to meet Linus' intentions for the direction of his robot. A balance in their collaboration is seen throughout their activity. They are both active and attentive to the other's suggestion, they negotiate and confirm each other's ideas, factors we interpret to strengthen their joint attention and affordances in the inquiry and in the didactic milieu. A bit further into the activity Anton comes up with a plan for their two robots to bump into each other (Figure 1):

Anton	And we can try to crash too!
Linus	What?
Anton	We can try to crash.
Linus	Yes!
Anton	Jannica! Do you know what I and Linus will do?
Jannica	No?
Anton	We're gonna crash! [Looks at the teacher with a happy face]
Jannica	Then you have to drive at the same time, or?
Anton	Yes
Jannica	How will you succeed in that?
Linus	I know what you should do Anton! You drive to there, then I drive two more steps and into you.

An important aspect of the teachers' roles in the didactic games going on between them and the children is their ability to connect to the affordances the children experience in the situation. When Anton and Linus tell Jannica about their intention to crash their robots into each other, she encourages their idea with the productive question "How will you succeed in that?". She continues the activity by helping them in their common endeavor by showing them the pause-button and how they can use it to reach the same position at the same time and asks questions about how they should continue. Through this, she challenges the children in their inquiry and learning and helps them to move forward in their intentions with their inquiry. Jannica recognizes the children's own affordances in the situation and builds on them in the didactic game.

Another example of how Jannica promotes a joint inquiry among the children is seen in the next excerpt. In the second step of the inquiry activity where the children freely create obstacle courses for the robots, Mimmi tries patiently, and on her own, to build a bridge in the shape of a V, turned upside down, with KAPLA®-planks. (Figure 4)

Figure 4. Mimmi builds a bridge of KAPLA®-planks for the Blue-Bot®.

The bridge collapses repeatedly when she puts her Blue-Bot® on it and eventually, she gives up. In the example below, she has put the KAPLA®-planks flat on the floor instead, like a mat for the Blue-Bot® to go on:

	[Mimmi seeks the teacher's attention by pulling her arm but since the teacher is in the middle of a conversation with Stella, the teacher ignores Mimmi. Mimmi instead programs the robot and starts it. She puts her hands over her mouth in excitement and anticipation when the Blue-Bot® starts going over her kapla-planks. The teacher now turns her attention to Mimmi's Blue-Bot® and watches it as it goes. Suddenly it stops for a short while, and then continues forward.]
Jannica	[Smiling] Was that a pause?
Mimmi	[Smiles and nods. She has programmed a pause after paying attention to the teacher talking to Anton and Linus about how to use the pause-button, previously. The robot continues forward and stops with its usual beep-sound when it has finished. Mimmi fondly claps her hands and looks at the teacher.]
Jannica	What happened to the bridge?
Mimmi	[Inaudible]
Jannica	What did you say?
Mimmi	It just broke there. [Shows with her finger over the kapla-planks and adjusts the mat she has built from them.]
Jannica	It just broke? How could we have made it so it would hold, then?
Mimmi	[Gets up from the floor and disappears off camera to collect something.]
Jannica	Yes, just get what you need! [Mimmi needed confirmation from the teacher to get the material she intended.]
Jannica	Does anyone have an idea how to help Mimmi build a bridge that holds when a Blue-Bot® goes on it? [Mimmi comes back with a box of blocks in different colours.]
Anton	Yes! You can build a bridge with this! [Leaves his own inquiry on the mat and takes a block from the box Mimmi collected.]

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Stella	I know! One can build… [Runs off to collect a plywood sheet that she comes back with.]
Jannica	Mimmi, look what Stella found!
Mimmi	That one's mine. [Takes her Blue-Bot® from the floor.]
Anton	[Anton aids in building a bridge by putting two kapla-planks on their ends on Mimmi's line of kapla-planks. He then returns to his own inquiry with Linus.]
Stella	You can do like this! Mimmi, you could do like this! [Stella has put the plywood sheet as an inclined plane against the box with kapla-planks. She gets no attention from Mimmi since Mimmi looks at Anton, but puts her own Blue-Bot® on the bottom of the inclined plane, facing upwards.]
Jannica	Look Mimmi, what Stella created, it's a bridge! [Points to the plywood sheet that Stella leaned against the box.]
Mimmi	[Takes her Blue-Bot® and walks over to Stella's bridge and places the Blue-Bot® next to Stella's on the inclined plane.]
Mimmi	Stella, should we have a competition, go up first?
Stella	No!
Mimmi	Try that?
Stella	No, I know! It should come DOWN first! That's what … [Puts her Blue-Bot® at the top of the plane, facing downwards. Mimmi follows her example with her Blue-Bot®.]
Jannica	Oh! Look! [Mimmi and Stella start to program their robots.]

In the excerpt we see how the teacher draws the children's attention towards Mimmi's activity, thereby creating means for joint attention and joint affordances in the situation. Anton and Stella both fall into Mimmi's intention to build a bridge and try to help her with it. Anton goes back to his and Linus' inquiry on the mat but Stella and Mimmi create a joint game and a competition, initiated by Stella's construction of an inclined plane. The creation of the competition may be viewed as a joint attention between the girls. However, this initial joint attention includes no joint affordance experienced by the girls in the situation, since Mimmi intends for the robots to go up the plane while Stella intends for them to go down. They agree on Stella's suggestion to go downwards and through this agreement, a joint affordance in the situation is established. Jannica follows their intentions and continues the didactic game by directing their attention towards a fair trial when the robots compete on the inclined plane:

	[The girls start to program their robots and Stella starts her first.]
Stella	[To Mimmi] Start.
	[Stella presses the start button on Mimmi's Blue-Bot® but it does not start. Stella's robot goes down the inclined plane and finish before Mimmi's robot even starts.]
Stella	I will win, I won. But we start over!
Jannica	Perhaps you should start at the same time.
Mimmi	I haven't started!
Jannica	Yours doesn't run? What's happening to yours?
	[The girls are programming again and the robots go fairly even downwards on the plane.]
Stella	[To her robot] Come on! Both came down on the same time! [Looks at the teacher with a happy face]
Jannica	Did you start them at the same time?

Stella notices the unfair trial when Mimmi's robot does not start, as she states that they must start over. The teacher underlines this by directing Stella's and Mimmi's attention to this important aspect of the didactic game, with the question "Did you start them at the same time?". Jannica's approach to direct the different children's attention to each other's inquiry creates a joint attention in

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the group and opens up for joint affordances.

When all the children in Caroline's activity have walked the arrow path, Caroline expands the didactic game and milieu by opening up for the children's own ideas in the activity:

Caroline	Now we have been robots. Is there anything else you could do with the path?
Alice	I know! You could make an obstacle course.
Caroline	An obstacle course. In what way could you make an obstacle course?
Alice	You can do like this, then you can go here … [Starts to re-locate the papers and arrows in the path a bit to the left and right so that a larger space is created between them. The children will need to jump or take larger steps to get to the next paper/arrow.]
Alice	Then you continue like that! So you have to walk like this, then like this, then … [Shows with her feet on the new path.]
Caroline	You re-build the path?
Alice	Mm
Caroline	Mm
Elias	You could also do like this that you can point to a paper … [Turns an arrow so that it points to a paper.]
Elias	… then the paper points to this paper. [Continues to build the path by turning the arrows in new directions]
Caroline	[Looks at the other children] Yes, 'cause a path could be placed a little here and there.
Children	[Nodding]

Caroline makes use of the children's agency and own ideas in this part of the didactic game. She encourages them to explain their thoughts and opens up for joint attention and joint affordance by confirming one child's idea to all children.

In summary, the analyzed STEM-activities points to several crucial aspects of how the teachers enable and promote the didactic game in their respective situations. First, the teachers and the children recapitulate the group's already established knowledge, that is, the didactic contract, around the Blue-Bots® and the stones and about what a robot could be. Thereafter, the teachers construct a didactic milieu of first teacher-led and then open free, but coached, inquiry, where the children's own thoughts and interests are important parts of the didactic game. By creating interest and teaching the children hands-on, as well as by expanding the learning milieu for both individual children and children working together, the learning game enables joint attention, joint affordances and common ground, i.e. joint action, to be created in the groups.

Discussion

During the implementation phase of the botSTEM project where teachers are trying out, evaluating and modifying the botSTEM activities, we have mostly experienced teachers choosing to start with unplugged versions of the activities, where the children 'program' each other. However, the results of the present study indicate the robots to be strong motivators in enabling joint actions among the children. Interestingly, the two teachers in this study make use of the same didactic strategies in their learning games, despite one including physical robots and the other not, in their teaching about programming. The employed strategies described above, and used for enabling joint attention and joint affordances in the situations, seem to work in both unplugged and digital (plugged) circumstances. Across the varying contracts and milieus in this study we experience the categorized strategies in both cases. It is therefore not clear that a generic recommendation would be to start with unplugged programming – it appears to work both ways. It will depend on the didactical contract and milieu set up by the teacher.

The children's investigations and inquiry taking place in this study can also be said to belong to what Eshach (2006) describes as 'domain-general knowledge' of science, aiming at the scientific work processes such as observations, experimentation, discussions, etc. The teacher's strategies for enabling joint action among the children can therefore be described as promoting learning of domain-general scientific knowledge, as well as promoting the didactic game. The coaching approaches seen in the analyzed activities of this study, where the teachers in different ways support the children in their thoughts and observations without providing them exact solutions, may also be seen as examples of what Eshach and Fried (2005) mean when they point to the role of a teacher as one that demonstrates how a comb will deflect a stream of water after the comb has been run through one's hair, rather than speaking of electricity. This kind of reticent coaching strategy has also been discussed as fruitful by Undheim and Jernes (2020) in their case study of technology-mediated story creation with two small groups of young children. The approach is similar to what Fleer et al. (2014) have called having a 'sciencing' attitude and it is a strategy we have discussed previously based on an interview with a preschool teacher after the implementation of a teaching sequence involving water phase changes and digital movie-making (Fridberg et al. 2018a). In the didactic game taking place, the teacher and the children move from the didactic contract involving their previous habits and knowledge of how to program the Blue-Bots® on the floor, to include e.g. programming them up and down inclined planes and cooperating around how two Blue-Bots® can be programmed to 'crash' into each other. The activity thus combines programming and scientific inquiry, or in other words robotics and domain-general scientific knowledge, and provides novel knowledge of how teachers may support learning of the S and T in STEM, in the preschool environment.

The competent child is a perspective that underlies the work presented here and the result indicates that in enabling the children with a power of acting, the learning game proceeds enabling the didactic milieu to develop. This is particularly noteworthy for the given examples of joint action among the participants in the didactic game, where the programming skills and important concept are experienced and instituted in several concrete situations with the Blue-Bots®, as also discussed by Sensevy et al, (2015). The role of the teacher in the didactic games is essential, and several examples are given here of the teachers' persistently maintaining a focus towards enabling development of the didactic milieu, based on the didactic contract and enabling joint actions both between the children and between children and teacher. An example of this is when the teacher Jannica coaches Mimmi to metareflect and express how she thought and visualized the counting of robot 'steps' into the farmhouse. However, note that the teachers here were aided in this by the children's interest in working with experimenting and robots, a comparable result to what was earlier found for experiments scaffolded by a computer tablet (Fridberg et al. 2018b). The pattern of interaction also exemplifies the importance of a teacher that listens to children's perspectives but at the same time challenges the children further by directing their attention towards what the teacher aims for them to learn about. This establishes a relationship between the children's thoughts and expressions and the intended learning in the activity (Fridberg et al. 2019).

A limitation of the study is that it only focuses two teachers and their respective child groups whereby more general conclusions are not possible. However, they are not exceptional cases and we consider the findings to be of interest when discussing teaching approaches for STEM education in early years education. Especially, for teaching, with what we describe as involving a didactic game with set, but dynamic learning goals.

Conclusions

The findings in this study point to fruitful didactic strategies for teachers to make use of when teaching STEM in preschool. The analyzed examples of teacher-led but child-centered approaches described have been found to enable and sustain joint attentions and joint affordances in both groups of children, and show promise for teaching STEM and programming, with and without digital tools. This makes the present study a good basis for discussions about what should constitute STEM education in preschool and the teacher's role in the same. There is a need for future studies of teaching involving programming and robotics including more specific intended objects of learning in the STEM-fields, i.e. using robots to learn about gravitation and friction. Implementations of newly

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developed botSTEM activities for early years with specified learning objectives for both robotics and different STEM contents will be analyzed during 2019. The analysis will have a specific focus on how learning of the involved STEM content can be scaffolded by robotics.

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RESEARCH REPORT

Evaluation Approach: Practice-Focused Middle School Science Modules

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Abstract: *Advanced Manufacturing and Prototyping Integrated to Unlock Potential (AMP-IT-UP) is a National Science Foundation (NSF) funded K-12 Math & Science Partnership (MSP) project with a goal of promoting math, science, and engineering learning through STEM integration-focused curricula. As part of this project, curriculum writers developed one-week modules providing instruction on a set of STEM practices within the context of the appropriate grade-level content. These STEM practices are grouped into strands labeled Experimental Design, Data Visualization, and Data-Driven Decision Making; the emphasis of each of these practice strands is, respectively, the collection of data, the representation of data, and the use of data to support complex decision-making. Nine one-week modules were created in the science domain, one focused on each practice strand at grade levels 6, 7, and 8. A parallel set of nine modules in the math domain were also created, resulting in a total of 18 modules. In this paper, we will focus on our evaluation of the effectiveness of these modules as they were implemented across four middle schools. We will present our methodology for evaluating this complex instructional effort. Data sources include online teacher enactment surveys, teachers' on-line posts, as well as classroom observations. Findings were compiled across these multiple data sources to provide detailed insights into curriculum functioning and teacher experiences. We will also provide some results from pre-post assessments of student learning, which were written for a subset of the science modules. Overall, the results provide detailed and valuable insight into curriculum functionality as well as evidence of significant increases in student learning in some modules. Findings from these data sources were used by curriculum developers to inform later iterations of the modules.*

Keywords: *K-12, STEM, evaluation*

The purpose of this paper is to describe a multifaceted evaluation of a set of one-week science and mathematics modules designed for use in middle schools. These modules provide students with instruction on, and experience working with, data-related STEM practices grouped into three clusters entitled Data Visualization, Experimental Design, and Data-Driven Decision Making. The practices in these clusters were drawn from the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013) and the Standards of Mathematical Practice (SMP) (National Governors Association Center for Best Practices, 2010). The modules are situated within the context of grade-level specific science and math disciplinary content. This evaluation was carried out by a team of education researchers and utilized multiple data sources. The core of the achievement of curriculum objectives is driven in part by the evaluation process used during the development of the curriculum. This study addresses how different sources of data can be used to evaluate whether or not the curriculum reached its objectives. The goal is to provide an evaluation process for curriculum development, which is a continuous iterative process carried out until the objectives are reached.

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The evaluation of the math and science modules was a complex research effort due to a number of factors. First, there are three science modules for each middle school grade level, for a total of nine distinct instructional science modules across grades 6, 7 and 8. These are accompanied by a parallel set of nine math modules; for this paper, we are focusing solely on the evaluation of the science modules. In order to be comprehensive, our evaluation needed to cover not only the STEM practices common to the modules, but also the logistical details and disciplinary core ideas specific to each module and its associated activities. Therefore, it was crucial that researchers developing the evaluation have a deep understanding of the content and flow of each module. Second, there were multiple aspects of the module implementation that needed to be evaluated: how the curriculum functioned in the classroom, teachers' experiences with implementing the modules, students' experiences participating in the modules, and the nature and extent of student learning that occurred during module implementation. Third, the logistical considerations associated with carrying out observations were nontrivial, as the module implementations occurred in over twenty classrooms in four middle schools, and data collection schedules required flexibility to accommodate changes due to school events.

This paper outlines the efforts undertaken to evaluate this complex curricular innovation while attending to the factors described above. Further, we provide an alternative and novel way of evaluating the quality of this complex curriculum by utilizing evaluation data from a variety of sources. A review of the literature yielded no comparable studies in which a variety of data sources were combined in this manner to inform iterative curriculum development. As such, we feel this description of our evaluation process represents a meaningful contribution to the literature. The goal of the paper is to detail our evaluation efforts, including its multiple components and how each was selected, designed, and executed. We will also discuss the manner in which the various evaluation data sources were compiled and used to inform later iterations of the curriculum design.

Project Overview

This paper describes an evaluation effort embedded within a larger project, titled "Advanced Manufacturing and Prototyping Integrated to Unlock Potential" (AMP-IT-UP). This project was a 5-year National Science Foundation (NSF) Math and Science Partnership (MSP) between a higher education institute and an urban-fringe school district within the same state. The goals of the partnership were to promote STEM integration in middle school engineering, math, and science classes, increase STEM relevance by emphasizing advanced manufacturing and data-driven problem solving, and ultimately to increase student engagement and academic achievement in math, science and engineering. A major component of AMP-IT-UP was the development, implementation, and evaluation of math and science modules that were implemented in core math and science classes.

In this paper, we describe a methods-focused approach and outline the various components of the multi-faceted evaluation effort undertaken to investigate the effectiveness of the modules. First, we provide an overview of the modules, briefly describing their development and highlighting their role within the overarching project. Next, we discuss our goals in evaluating this complex curricular component, the instruments and methods involved in the evaluation, and how the choice of evaluation methods and instruments helped us to achieve these goals. We further discuss how the evaluation data were utilized for curriculum development. We conclude with a brief discussion of a small subset of sample results, presented not in service of drawing summative conclusions or providing a comprehensive overview of the analyses and results, but rather to offer some insight as to how the evaluation results were synthesized and used within the iterative curriculum development process employed in this project.

Module Description

Each module focuses on a particular cluster of STEM practices and on grade-level appropriate disciplinary content, and presents student teams with an inquiry-driven problem or challenge. The three STEM practice clusters, labeled Experimental Design, Data Visualization, and Data-Driven Decision Making, emphasize, respectively, the collection of data, the representation of data, and the use of data to inform decision making. Standards included in the modules, for both STEM practices

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and disciplinary core ideas, were drawn from the Next Generation Science Standards (NGSS Lead States, 2013) and the Standards of Mathematical Practice (National Governors Association Center for Best Practices, 2010). The STEM practices in each cluster are listed in Table 1. The curriculum designers intended the STEM practice clusters to unify overlapping skills across these national science and math standards, allowing for an investigation of integrated STEM learning.

Table 1.
Module practices and associated standards.

Experimental Design	• Planning and Carrying Out Investigations (NGSS Practice 3) • Make Sense of Problems (SMP #1); Use Appropriate Tools Strategically (SMP #5)
Data Visualization	• Analyzing and Interpreting Data (NGSS Practice 4) • Make Sense of Problems (SMP #1); Model with Mathematics (SMP #4)
Data Driven Decision Making	• Constructing Explanations and Designing Solutions (NGSS Practice 6) • Engaging in Argument from Evidence (NGSS Practice 7) • Make Sense of Problems (SMP #1); Construct Viable Arguments (SMP #3)

The modules also each support development of student understanding within disciplinary core ideas taught in middle school science (i.e., earth science, life science and physical science) and math (i.e., statistics, geometry, and algebra). It should be noted that these are one-week modules, and as such, are not in of themselves sufficient to promote proficiency with or mastery of these disciplinary core ideas. There are 18 modules across the three grade levels, and each requires approximately one week of instruction. A student receiving instruction on the full complement of modules would complete six modules per grade level, three in math and three in science. The full set of modules is presented in Table 2.

Table 2.
AMP-IT-UP Science and Math Modules

	Science Modules		
	Experimental Design	Data Visualization	Decision Making
6th	Lava	Earthquake	Winter Weather
7th	Oil Spill	Deep Sea Ecosystems	Coral Reef
8th	Marine Snow	Helmet	Skate Park
	Math Modules		
	Experimental Design	Data Visualization	Decision Making
6th	Packaging	Whale	Automated Packaging
7th	Board Game Piece	Crab Aquarium	Manufacturing Quality Control
8th	Clean Energy	Hot Shots	Power Finance

The three, one-week science modules developed for each grade level were in part informed by the approach used in Kolodner et al.,'s (2003) Launcher Unit, in which the key aim is providing instruction on critical skills rather than domain-specific content. The research of Kolodner et al.,

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demonstrates the impact of launcher units: as students engage in project-based contextualized learning through skill-focused units, they have repeated opportunities to practice with and reflect upon the skills they are building, while simultaneously seeing the connection of these skills to science concepts. These units model and establish terminology, rituals, and norms that are later repeated in more concepts-focused units, and research suggests that launcher units promote transfer of skills and development of science conceptual knowledge (Kolodner et al., 1998; Kolodner et al., 2003). Because the one-week duration of modules limited the extent to which they would be able to fully present and cover substantial science and math content, we saw an opportunity to instead use the modules in a launcher unit-like fashion to develop understanding of critical and unifying skills across the three STEM practices.

Science modules were designed with the intention that teachers would implement them either early in the school year, to introduce students to practices that would be iterated upon and developed throughout the school year, or as an introductory experience before in depth instruction on relevant disciplinary content. The math modules were designed to be implemented during the teaching of the specific domains of content that they covered. Actual timing of module implementation varied across teachers based on their scheduling preferences and other logistical constraints.

Module implementation. The modules were rolled out gradually over the course of the project, with all 18 modules being implemented during Years 4 and 5. Teachers received professional development on the modules primarily at a summer institute held each year at a location within the school district. For this paper, we will focus on the nine science modules. This is largely due to their being in a more advanced stage of development during our focal year of curriculum implementation as compared to the math modules. This is because the science modules were fully developed and piloted earlier in the project than most of the math modules, and had been iterated upon more times than were the math modules prior to the focal school year.

The 2016-2017 school year represents the first year in the project that the full set of modules was available for implementation. During the 2016-2017 school year, 20 regular middle school science teachers and five special education science teachers implemented one or more of the science modules. During the 2017-2018 school year, 21 regular middle school science teachers and five special education science teachers implemented one or more of the science modules. In the early years of the project, participation in AMP-IT-UP was voluntary. However, by Year 5 (2017-2018), all middle school math and science teachers in the district were instructed to use the materials in their classes. Because of the large turnover of teachers in the district every year, there were some newly hired teachers who had not received instruction on the materials. We attempted to address this issue by providing professional development on the modules after the school year had started for late hires. Additionally, teachers who had prior experience with the modules often provided guidance to new teachers who may have missed the summer professional development. Despite these efforts, each year there were some teachers who did not implement the modules due to having missed the summer professional development.

Module instructional materials. The project provided teachers with all materials required to teach a module: a student content booklet (called the Student Edition), a set of student worksheets (separate from the booklet), two teacher curriculum guide booklets (called the Teacher Editions; one of these is a facilitation guide for module implementation, and the other is a preparation guide for pre-facilitation prep), videos, links to required computer simulations, supplemental materials, and supplies and/or manipulatives needed for the module implementation. The Student Edition includes the student text, instructions for activities, and guiding questions for discussion. Student worksheets are separate from the booklets and include graphing exercises, space for students to write procedures and record the data they collect, graphic organizers, and space for communicating evidence-based decisions or recommendations.

Two Teacher Editions were developed to aid teachers in implementing the modules. The first is an Annotated Teacher Edition, which is a copy of the Student Edition with notes for the teacher added throughout. Teachers use this Teacher Edition during instruction to follow along with

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students as they progress through the Student Edition. The Annotated Teacher Edition also provides "in the moment" tips for instruction and questions to ask students.

The second Teacher Edition is a preparatory guide that was developed halfway through the project based on the needs of our teachers; it was designed to align with the format of their lesson plans. The preparatory guide Teacher Edition contains the content teachers would need to aid them in lesson planning (e.g., curriculum standards) and to help them prepare for implementation. The preparatory guide also includes detailed instructions for setting up manipulatives and computer simulations for modules that utilize these activities, as well as expectations for student and teacher activities.

Each preparatory guide includes an overview of how the module maps onto the BSCS Science Learning 5E Instructional Model (Bybee, 2015), which was a pre-existing district-level requirement for teachers' lesson plans. Constructivist theory as it relates to learning is at the root of the 5E model, a sequence which consists of the following five phases: Engage, Explore, Explain, Elaborate, and Evaluate. Each phase has specific functions through which teachers and learners progress in support of achieving educational objectives (Bybee, 2006). Mapping the module curriculum onto the 5E Instructional Model provided teachers with an aid for implementation and an overview of expectations for student and teacher activities. Furthermore, the use of this model presented the module curriculum within the context of a framework with which these teachers were already familiar, and aided in their lesson planning by mapping the module curriculum onto the required organizational structure for their lesson plans.

Module examples. This section presents a brief overview of three sample modules, including one from each grade level and one from each of the STEM practice clusters. Please see Appendix A for information on accessing all modules and associated materials via our project website.

In the 6th grade Experimental Design module, titled "Molten Madness: Lava Challenge," students are challenged to help determine the speed of lava flow on land in order to develop evacuation plans in the event of a volcano eruption. This instructional approach of framing the module within the context of an overarching challenge students are tasked with solving is repeated across all modules. This module emphasizes writing procedures, which fits within the focal STEM practice cluster of Experimental Design. Students are asked to write their own procedure to measure the "lava" flow in their models, which use a plastic plate and dish soap to model the flow of lava down a mountain. Please see Appendix B, part 1, for a screen shot of the page of the student edition in which students are given instructions for writing their initial procedure.

Generally, students write poor procedures at first; when students follow these low-quality procedures, in which important details are frequently ignored or not properly controlled, the resulting data varies widely across students. This is made clear to students when the data generated from their initial procedures are displayed on a histogram, providing a visual of the widely varying data. Over the course of the module, they re-write their procedures, improving them as they learn to control variables (e.g., the amount of soap, how they record elapsed time). As they redo the experiment, the results become more consistent across students. This module also provides instruction on the practice of modeling. Many students and teachers have the misconception that in order to address this challenge, they would need to create a model of a volcano, complete with lava flowing from its center. This module demonstrates that a simple model of the flow of liquid across a surface is sufficient.

The 7th grade Data Visualization module, titled "Deep Sea Ecosystems", is set within the context of research on coral reef health after the Deep Horizons oil spill in the Gulf of Mexico. In this module, students analyze a set of photos of deep-sea coral taken over time by researchers studying the after-effects of the oil spill. The students create a rubric to evaluate the health of coral, and then use a variety of visual representations of their data to present and emphasize different aspects of their coral sample's health. The multiple visual representation options presented in this module, including the use of temporal and pictorial data, align with its focus on data visualization. Please see Appendix B, part 2, for a screen shot of the page of the student edition in which students are given the challenge description for this module.

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The 8th grade Data-Driven Decision-Making module, titled "Skate Park", tasks students with analyzing crash helmet strength through the use of a simulation, and then selecting the best helmet for a skateboard rider. During the activity students evaluate the cost and level of protection that different helmets provide, as well as the budget and risk level of the different riders. This focus on compiling and synthesizing various sources of information to make and defend a decision that is intentionally messy aligns with this module's focus on data-driven decision making. Please see Appendix B, part 3, for a screen shot of the page of the student edition in which students are asked to share and discuss with the class the helmet data they have collected.

Methodology

The curriculum development and research approaches adopted for this project were informed by the design-based implementation research (DBIR) framework (Fishman, Penuel, Allen, Cheng, & Sabelli, 2013), which holds as a central tenant "a commitment to iterative, collaborative design" (Fishman et al., 2013, p. 142). The interplay between the data collected on curriculum implementation, the reporting of this data to the curriculum team, and the use of this data to inform subsequent iterations of the curriculum exemplifies DBIR through its emphasis on both collaboration and iteration, with the results of a collaboratively designed evaluation effort directly informing multiple iterations of the curriculum.

Evaluation of a complex intervention such as the large, multi-faceted, multi-year curriculum development and implementation work undertaken in this project is a difficult endeavor; the evaluation was designed to satisfy several goals. The primary goal of the evaluation approach was to evaluate the overall extent to which these modules reached their objectives; more specifically, the goals were as follows:

1. to collect data on the logistics and challenges involved in teachers' module implementations;

2. to assess student learning of the content and practices covered in the modules;

3. to provide general formative feedback to the curriculum developers to inform revisions to future versions of the module as part of an iterative cycle of research on, and further development of, the module curricula.

This evaluation sought to provide information on various aspects of the module implementations, as well as insights into the perceptions of, and impacts on, both teachers and students as a result of their experiences with the modules. To this end, data were collected via numerous instruments from various stakeholder groups to allow for synthesis and comparison of findings across multiple data sources. It is our hope that by utilizing four distinct data sources which vary across method (quantitative, e.g., surveys and assessments; and qualitative, e.g., classroom observations and open-ended online posts), people (students completed assessments, teachers completed surveys and online posts, and both students and teachers were involved in classroom observations), and time (these data were collected at various time points across the focal school year), we will enrich our study and provide robust evaluation data on which to base curriculum development decisions (Flick, 2009).

Student learning of the STEM practices and disciplinary content presented in the modules was assessed via a single source, the pre and post assessments. The student assessments were heavily focused on STEM practices to allow us to directly measure student gains in knowledge and application of the STEM practices over the course of the module implementation. We captured teachers' inclusion of the STEM practices within the three clusters, as well as additional elements, in their module implementations via both their self-reports of what they did and did not do during the implementation in the online surveys and co-lab posts, as well as our own observations of whether and how the practices were taught during our classroom observations. This utilization of data across multiple sources allowed for a complete and multi-faceted picture of module implementations. Furthermore, the use of various data sources allows for increased confidence in our findings.

Student Pre-Post Assessments

To measure student learning over the course of the module, multiple choice (MC) assessments were developed and administered in a pre-post format (i.e., the same assessment was given to students both prior to and immediately after the module). Although researchers and practitioners have frequently pointed out the limitations of MC items (e.g., Klassen, 2006), well-designed MC-based assessments can provide valuable insights into student understanding without the need for time-consuming scoring procedures (Haladyna, 1999; Sadler, 1998).

All MC items were written by members of the research team and reviewed and edited by members of the curriculum team to ensure an appropriate match to the module curriculum practices and content. MC assessments were developed for the Data Visualization and Experimental Design modules only; it was determined that the focus on written content and defending one's decision using data inherent in the Data-Driven Decision Making modules did not align well with a MC assessment. As part of planned future work, student learning in Data-Driven Decision Making modules will be assessed through analysis of student work products.

Initially, MC assessment items focused solely on the clusters of STEM practices and did not address the module-specific content. However, in the early years of using these assessments, teachers expressed concerns that the assessments did not measure what they were teaching in the modules, which we interpreted as a face validity (Nevo, 1985) issue. As a result, module-specific MC items were written for some modules. Some of the general STEM practice-focused items were retained for these module-specific assessments, and items specific to the STEM practices within the context of the specific module were added. For example, this was the case for Deep Sea Ecosystems (7th grade Data Visualization module) and Helmet (8th grade Data Visualization module), which had four module-specific items and three module-specific items, respectively, added to the existing Data Visualization assessment items. Two sample MC items from the 7th grade Data Visualization module, one general practice-focused item (item 1) and one module-specific item (item 2) are presented in Appendix C.

The practice-focused items are intended to assess students' ability on a given cluster of STEM practices irrespective of the specific module content. As such, these items were written to apply generally to the STEM practice cluster to which they correspond, and can be used across module assessments for all modules on the given STEM practice. The Data Visualization STEM practice-focused item provided in Appendix C (item 1) asks students to use data on cafeteria food sales by day of the week to answer a question about meal planning for the cafeteria staff, specifically helping the staff select the food with the lowest sales to be eliminated from the cafeteria offerings. Students must be able to interpret what the data in the table represent by reading the row and column headers in the table, recognize that they will need to add the sales of a given food over the five days of the week, and identify which food has the lowest sales for the week. Per the NGSS Practice description in which this STEM practice is rooted (NGSS Practice 4: Analyzing and Interpreting Data), students in grades 6-8 should be able to "construct, analyze, and/or interpret graphical displays of data and/or large data sets to identify linear and nonlinear relationships" and "analyze and interpret data to provide evidence for phenomena" (NGSS Lead States, 2013, p. 9). This assessment item asks students to demonstrate their ability to interpret a data table to determine the rank ordering of the various foods in terms of weekly sales, and to use this data to provide evidence to advise cafeteria staff on which menu item to eliminate.

The module-specific assessment item provided in Appendix C (item 2) relates directly to the data visualization content students are instructed on and asked to apply as they work through the module challenge. In this challenge, students construct a rubric to evaluate the health of coral within a marine ecosystem affected by an oil spill. They use the rubric they construct to evaluate and compare data from different time periods (temporal data) and from different geographic areas (spatial data). This module content directly ties to the NGSS practice component stating that students should be able to "use graphical displays (e.g., maps, charts, graphs, and/or tables) of large data sets to identify temporal and spatial relationships" (NGSS Lead States, 2013, p. 9). The assessment item specifically asks students to consider what a rubric is and what situations it would and would not be useful within. This content about what a rubric is and what it can be used for is taken directly from the module, and is appropriate for this module assessment only given its close ties to the module content, as opposed to the more general STEM practices. Please see Figures 1 and 2 for a visual representation of these two sample assessment items and their underlying links to the STEM practices and corresponding NGSS practice content.

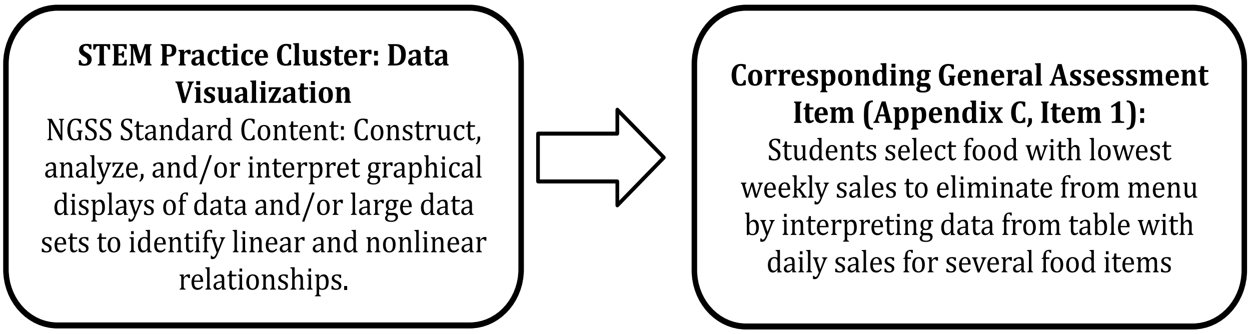

Figure 1. STEM practice and NGSS standard associated with sample assessment item 1 (Appendix C)

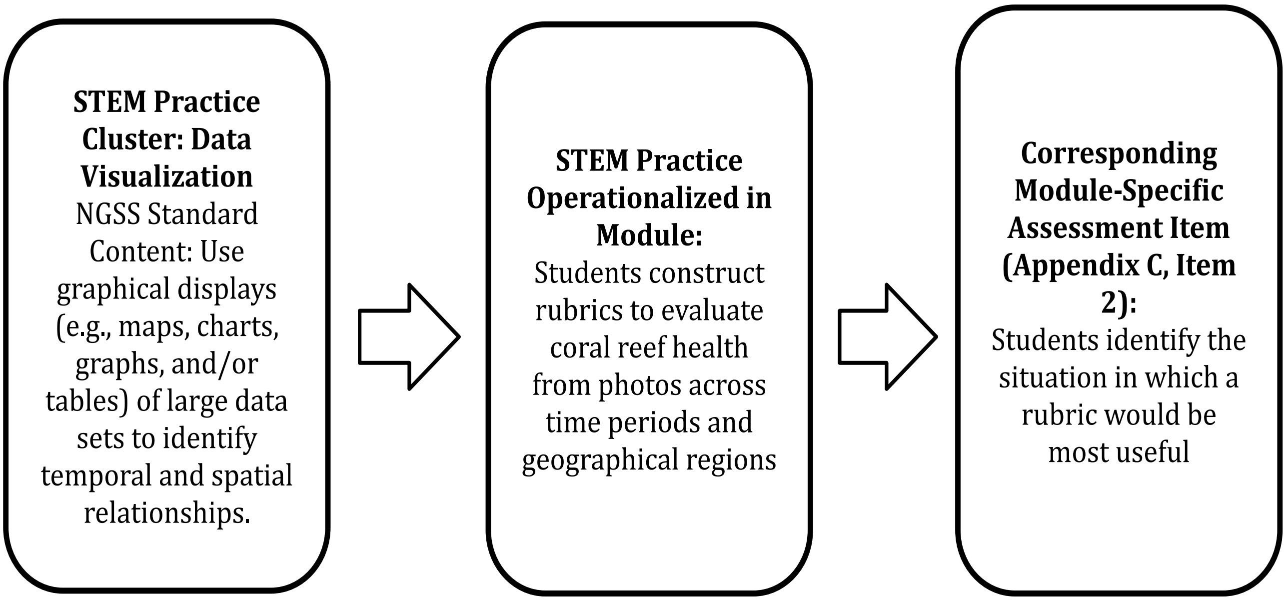

Figure 2. STEM practice and NGSS standard associated with sample assessment item 2 (Appendix C)

These assessments take approximately one 50-minute class period or less to administer and range from 4 to 10 items in length; the items vary in cognitive complexity and required skills/ computations, which is why the assessments vary widely in total number of items. For the purposes of this paper, 2016-2017 school year student data is used. The six science module assessments were each administered to between 278 and 501 students across the four middle schools. Between four and eight teachers administered each of the module assessments in their classes.

Teacher Enactment Surveys

Enactment surveys were developed for each module based on the corresponding teacher curriculum guide (Teacher Edition), which provides teacher-specific instructions as well as the general layout and flow of the module. These surveys are designed to elicit teacher accounts of specific components and activities of the module, including yes/no items asking whether teachers completed various activities, and open-ended items for teachers to provide feedback and additional details about how they completed various activities. The survey also includes questions about module logistics such as start and end date and duration of each section within the module, as well as questions about student engagement and any adaptations teachers made throughout the module. Sample enactment survey items from one section of the 6th grade Experimental Design module are shown in Appendix D. Enactment surveys were administered online via Survey Monkey and took roughly 20 minutes to complete. Links to each module-specific survey were e-mailed out by project staff when the teacher completed a module. Teachers who had not completed the surveys were prompted to do so.

Classroom Observations

Classroom observations were included in the research design in order to allow researchers to view curriculum implementation as it unfolded in the field. Teachers provided their perceptions of their module implementations via surveys; classroom observations provided another source of information on curriculum implementation and enabled researchers to study implementations in more detail and contrast what was directly observed with what teachers reported. In their text on participant observation, Dewalt & Dewalt (2002) describe observation as follows: “the researcher explicitly and self-consciously attending to the events and people in the context they are studying” (p. 68). Observations are considered by some researchers to be the most rigorous means of studying implementation (Ruiz-Primo, 2006).

Classroom observations, conducted by members of the research staff, were guided by protocols created directly from the enactment surveys (discussed above). Protocols were utilized in order to guide the observer to focus on recording specific details that would be most useful for informing curriculum iteration, given that “all observation is partial” (Agar, 1996; cited in Dewalt & Dewalt, 2002, p. 76). Furthermore, the protocols were used to help promote consistency across observers given that a team of several researchers carried out the observations. These protocols were comprised primarily of checklists for specific activities (e.g., reading text passages, showing videos, guiding class discussions, running simulations, completing worksheets, etc.) that the observer could indicate Y/N as to whether the activity occurred during the observation. Observers also recorded the start and end times for each section as well as notes on how teachers guided students through reading text and class discussions. Additional notes related to modifications of the module curriculum, challenges encountered by teachers during the module implementation, and any other relevant occurrences were also included in the classroom observation protocol. These protocols were completed during each classroom observation. Nearly all science modules were formally observed at least once during the time period between Spring, 2016 and Spring, 2017. This time period was targeted because by this point in the project, most modules had at least their first iteration finalized and ready for full implementation. Four researchers carried out this series of observations.

Co-Lab Posts

Teachers were asked to respond to a series of open-ended prompts about their experiences with the module. These responses were done in the context of an online forum hosted on a Google site called the “co-lab”. Co-lab posts provided teachers an opportunity to provide more holistic feedback on the module implementation, focusing on details and module components of their own choosing, as compared to the more scaffolded and directed feedback elicited in the enactment surveys. The co-lab posts complemented the enactment surveys and provided researchers with a means of contrasting teacher data across multiple sources.

The prompts to which teachers responded in the co-lab posts were written by the curriculum developers and were largely specific to either the module itself or the STEM practice it addressed. A prompt asking about obstacles and barriers to implementation was included for each module. General topics on which these prompts focused across modules include student misconceptions around and understanding of the STEM practices and specific adaptations that teachers made to the module. The supportive, collaborative, and informal nature of the co-lab setting was intended to provide a space where teachers would feel comfortable sharing both their positive and negative experiences with the modules. Sample prompts are provided in Appendix E.

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Another important feature of the co-lab posts is that they served as a mechanism for teachers to share their experiences with, and feedback on, the module with each other. Teachers are distributed across four middle schools within the county, and they rarely have a chance to meet with teachers outside of their school, other than at the summer institute. The co-lab posts allowed teachers to learn about the experiences teachers outside of their schools had with the modules, and to gain insights about possible adaptations, additional materials and resources, etc.

Results

Over a period of several academic years, various types of data on the module implementations, teacher and student perceptions of the modules, and student learning were collected, analyzed, and shared with the curriculum developers; curriculum developers then used these findings to inform subsequent iterations of the modules.

While this paper is intended to focus on the overall evaluation approach and methodology, we present illustrative results from the module evaluation here to demonstrate the outcomes of the various components of the evaluation effort and how the results were compiled and shared to promote iterative curriculum development.

Student Assessments

Analyses using models based on Rasch measurement theory (Rasch, 1960) were used to test both the psychometric properties of module assessments and also to examine the degree to which there was evidence of improvements in student achievement on these assessments over the time period from before instruction to after instruction (approximately one-week duration in most cases). The results of this validation effort indicated that overall, the items functioned properly, in that their functioning aligned with the expectations of the Rasch models.

Pre-post comparisons were available for the six science modules with assessments implemented during Fall, 2016 (the three Data-Driven Decision-Making science modules did not have assessments due to their focus on a practice that does not lend itself well to a brief multiple-choice assessment). Across all students who participated in the module administration, positive achievement gains were evident for all six science modules implemented in Fall, 2016. These gains range in size from 0.09 to 0.55 logits; of these, the gains were statistically significant at the level of $p < .05$ for three of the modules.

However, we note the limitations of this pre-post design in which a control group was not used. Test effects, in which improvements arise from prior exposure to the test, could be present in our data because the same version of the test was used in the pre and post administration (Marsden & Torgerson, 2012). Issues of maturity, in which students improve simply by virtue of getting older, and history, whereby improvements are driven by simultaneous experiences external to the intervention, should be minimized by the short duration (one week in most cases) between the pre and post administrations (Marsden & Torgerson, 2012). Additionally, we did not measure more distal knowledge retention through the use of a post test administered at some further time point from the intervention's conclusion. A more robust design would include the use of a control group and/or a longer time horizon post-test; these are design elements we will consider including in future work.

Classroom Observations, Enactment Surveys, and Co-Lab Posts

Classroom observations. Classroom observations allowed researchers to directly observe module implementation taking place in the classroom. In many cases, observers noted smooth and well-functioning implementations, successful utilization of teacher additions, effective modifications to the curriculum, and high levels of student engagement. For example, the 7th grade Data Visualization module asks students to use rubrics to evaluate the health of organisms within deep sea ecosystems. The curriculum initially included an example related to criteria for safe driving in an effort to familiarize students with the notion of using a rubric. The observer described the limitations observed when the original rubric activity was used, noting that the teacher supplemented the

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module with an additional rubric activity (for evaluating the quality of hamburgers) that seemed more relevant to students:

> Students are not old enough to drive, and needed more rubric examples. Maybe a more relatable example?....[the teacher] had to provide a lot of additional scaffolding for the rubric, and how to use rubrics. She created the highly relatable McDonald's rubric…

In some cases, researchers observed logistical difficulties related to problematic manipulatives, student and/or teacher confusion driven by insufficient or unclear instructions, and activities with components targeting a difficulty level that exceeded many students' ability levels. One example of this occurred during the classroom observation of the 7th grade Data-Driven Decision-Making science module, which focuses on weighing the economic benefits of fishing and tourism against their potentially negative effects on the health of coral reefs. An activity in this module uses plastic counters to enable students to run a population simulation. During this simulation, the observer noted:

> Students in some cases needed extra counters for the 'reproduction' events at the start of each year – after a while, [the teacher] realized this and told students she had extra counters for this situation. But some students had already proceeded through a few years of the simulation without replacing the counters as specified because they did not have them in their discard counter. We may want to consider revising instructions to make clear to teachers and students that they may need to get additional counters during the simulation.

In this case, observation notes pointed to a somewhat minor component of the instructions that was nonetheless critical to students' successful progress through the simulation, and suggested that this part of the instructions needed to be clarified and/or emphasized given that it was initially overlooked by both students and the teacher. The observation notes also indicated additional problems occurring during this activity that resulted from the teacher having set up and distributed the manipulatives incorrectly prior to the students beginning the activity. This finding suggested a need to clarify instructions in the Teacher Edition and perhaps emphasize the importance of correct set-up for this particular module during professional development sessions.

Enactment surveys and co-lab posts. Multiple teachers often noted the issues apparent in our observation data in their enactment surveys and/or co-lab posts, allowing researchers to synthesize data across these sources and pinpoint problematic areas within the module curriculum. Echoing the observer note above about replacing counters during the population simulation, the same teacher wrote in her co-lab post:

> I also adjusted students visiting the 'Pet Store'. Some of my students were not making the connection to come pick up extra fish. If I had to choose any part to be the most difficult, it would be the discard and replace the population.

Another teacher provided similar feedback regarding general student confusion during the simulation activity, noting:

> The students were so confused during the Sorting/Counting section. I had to explain the process to the students numerous times before they actually began to grasp what should be done or how many organisms would be removed.

Receiving similar feedback from multiple teachers in the co-lab posts served the dual purposes of helping the research and curriculum teams hone in on points of confusion across multiple classrooms and also providing teachers with the supportive feeling of not being alone in their challenges with the modules.

Co-lab posts and enactment surveys also provided evidence of instances where the curriculum was working exactly as the curriculum writers intended. In the 6th grade Lava Challenge Experimental Design module, students write their own procedures to model how lava flows down

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a mountain. The intention of the module is that students' initial procedures are inconsistent and not sufficiently detailed, which results in a wide spread of data collected across student groups. As students refine and improve their procedures for subsequent trials, the data should become more uniform. This approach requires teachers to allow students to flounder a bit early on in the module; this is something teachers often shy away from, preferring instead to correct students' work immediately or prevent them from making mistakes in the first place. Evidence from the co-lab posts and enactment surveys shows that teachers embraced this component of the module:

> During the first trial, I did not give students input on their procedures. I wanted them to feel lost in a way. I wanted them to learn from their mistakes. If they had vague procedures, they had a difficult time doing the trials. They then learned the hard way that they need to write more specific procedures. – Enactment Survey Response

> We reviewed the procedures, but I let the students complete their own procedures…If they weren't detailed, they were lost when they were completing the experiment. This is memorable. – Co-Lab Post

Enactment surveys also provided specific timing details from multiple teachers for each module, allowing curriculum developers to tailor the module's activities as needed to reliably fit within one week of instructional time. The preparatory guide Teacher Edition also included pacing information for each section. Those pacing times came directly from what teachers reported in the enactment surveys, giving more credibility to the Teacher Editions.

The yes/no checklist allowed examination of which, if any, activities were being skipped by teachers. As an example, in the introductory section to the Deep Sea Ecosystems module, there were several suggestions for activities and resources for teachers to provide additional content beyond just the text in the Student Edition: a provided website with trivia questions, a provided website about the Deepwater Horizon oil spill, and an opportunity to supplement with ecology-related vocabulary and content of the teacher's choosing. Of the five teachers who completed this module in Fall, 2016, these suggested activities were completed by four, three, and three teachers, respectively. Each teacher skipped only one of these activities, suggesting that they considered the various options and selected those that worked best for them.

Module Reports

Formal module reports were created for each module administered during the 2016-2017 school year. All module evaluation products described above were compiled in these reports. The research team distributed these reports to the curriculum team, and then held a joint meeting in which the module evaluation results were presented and discussed with the curriculum developers. The contents of these reports were then taken into consideration during the revision process of modules for the 2017-2018 school year.

Discussion

There are numerous examples of instances in which module feedback from one of the data sources described above directly informed a revision to the subsequent version of the module curriculum and also helped curriculum developers and researchers evaluate the extent to which the curriculum reached its objectives. One such example occurred with the Deep Sea Ecosystems Challenge, which is the 7th grade life science Data Visualization module. During this module students learn how to analyze images and quantify data from these images. One activity involves students creating a rubric to evaluate two images. Originally, students analyzed images of what would be considered safe driving and unsafe driving. Teachers reported that students struggled with this rubric activity because they could not relate to driving. To combat this problem, one teacher replaced the driving photos with her own images of hamburgers instead. As a result of the finding that the driving related rubric did not resonate with students, the curriculum was revised to include the teacher-created sample rubric for what makes a good hamburger, and the safe driving sample

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was eliminated. The observation notes in this case provided the curriculum team with both evidence of a problem with a component of the curriculum as well as a solution one teacher had created to deal with the issue.

In another example, consistent issues related to confusion with instructions and manipulatives that were noted in the coral reef population simulation led curriculum writers to make changes to both the student and teacher materials. The curriculum team created separate student handouts with detailed procedures for the activity, enhanced both teacher guides with tips and suggestions for navigating the activity, and created a separate highly detailed instruction guide for preparing materials, to ensure proper setup of the manipulatives. For this module, the manipulatives themselves were also changed due to teacher feedback, from split peas to plastic counters that were more uniform in size and shape and were easier for students and teachers to work with.

The collection of data across these multiple sources allowed for the synthesis of findings regarding successful and problematic areas within the curriculum for each module. Sharing these findings in a concise and timely manner with the curriculum developers supported an iterative development cycle in which data directly informed the subsequent iteration of each module. This micro-level approach, focused on specific aspects of teacher and student experiences within the modules, provided insights that a more macro approach would not have allowed for. These insights guided the creation of versions of these modules in which elements leading to confusion and problems were clarified and improved upon. This multi-source data collection effort aligned well with the complexity inherent in the project, and directly supported the optimization of the curriculum, activities, and materials for each module.

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Appendix A

All modules and associated materials are available for free download via our project website. The website can be accessed using the following link: https://ampitup.gatech.edu

Appendix B

Sample Module Pages from the Student Editions

Part 1: Procedure Writing Instructions, 6th Grade Experimental Design Module

6EDS Lava Challenge

Procedure:

1. Spend 5-6 minutes discussing and creating a procedure for measuring the time it takes for lava to flow with your group.
   a. You can use the materials listed here to design and follow a procedure to determine how much time it takes the lava (soap) to flow across the surface of the plate. Additionally, you must complete at least six trials during your investigation, and record the data after each trial.
2. Write your procedure on your *Investigation Sheet 1*.
3. Raise your hand for your teacher come by to make sure that you have recorded your procedure and are ready to begin your investigation.

Materials

- Plastic Plate
- Model Lava (dish soap)
- Small Paper Cup (lava flow)
- Sharpie marker
- Stopwatch or timer
- Ruler
- Paper Towels
- *Investigation Sheet 1*

Part 2: Challenge, 7th Grade Data Visualization Module

1.4 THE CHALLENGE

ECOGIG's goal is to track the long-term impact of the oil from the Macondo Well explosion on the deep sea ecosystem. Although there may have been little or no oil seen on the beaches in the years after the oil spill, this is not true of the seafloor. Due to the coral's slow growth, it may take many years for the corals to show the full extent of the damage from the oil spill. Therefore, the ECOGIG team conducts research cruises each year to take pictures of these coral communities and evaluate their health.

The ECOGIG scientists have several images of different P. biscaya colonies from the Gulf of Mexico over the past six years since the Macondo Well blowout. The scientists want you to assist in the analysis of these images to determine which deep-sea ecosystems are recovering and which ecosystems have suffered the most damage. Watch the video of the ECOGIG team involved in your challenge assessing conditions four years after the Deepwater Horizon Spill.

Part 3: Class Discussion, 8th Grade Data Driven Decision Making

2.2 SHARING THE HELMET DATA

SkateTech provided your class with six helmets to test out in the skate parks. Your group only tested one of them so you are currently missing data from the other five helmets. All groups will need to share their helmet energy absorption data with the rest of the class. This way the entire class has the data about all the helmets.

Procedure:

1. Record the amount of energy each helmet absorbs in the table provided in Part C of your *Helmet Tests* student sheet.

?

Discuss these questions as a class:

1. What helmets offer the most protection?
2. What helmets offer the least protection?
3. Are there any helmets you think you should not consider for any of the skaters? Why or why not?

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Apendix C

Sample Assessment Items, 7th Grade Data Visualization Module

Use the following information to answer question 1.

You have collected data from your school's cafeteria on the quantities of certain types of food sold each day within a given week. Here are your data:

Day	Pizza (# slices)	Hamburgers	Caesar Salads
Monday	100	50	200
Tuesday	150	50	150
Wednesday	200	100	100
Thursday	50	200	50
Friday	200	150	100

1. The cafeteria is considering removing the food that was eaten the least for the week. Which food should they eliminate?

   A. Pizza

   B. Hamburgers

   C. Caesar Salads

   D. Pizza & Hamburgers (they have equal mode values)

2. In which of the following situations would a rubric be most helpful?

   A. Searching for an online resource

   B. Designing an experiment

   C. Evaluating your classmates' presentations

   D. Writing a report on the results of your research

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Appendix D

Sample Enactment Survey Items, 6th Grade Experimental Design Module

Section 1.2: Exploration & Section 1.3: What Did They Find?

9. Please indicate whether you completed the following activities:

	Yes	No
Guided students through text on p. 3 to check for understanding	○	○
Used the website provided in the TE ("where did the deepwater horizon oil go?") to supplement the text	○	○
Showed Video 1, ECOGIG: Deep Sea Life: Corals, Fishes, Invertebrates	○	○
Guided class discussion of questions in box on p. 3	○	○

10. If you guided students through the text, please provide a brief description of how you did this (e.g., read all text vs. some text, read as a group vs. read individually, students took notes on text vs. didn't take notes, etc.). Please specify if your approach varied across your class periods, and explain why.

11. If you guided a class discussion described in the questions above, please provide a brief description of how you did this (e.g., how you began the discussion, whether students discussed in groups or as a whole class, whether students wrote down their thoughts individually, etc.). Please specify if your approach varied across class periods, and why.

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Appendix E
Sample Co-Lab Prompts

Prompts specific to the Lava module

- Were you able to get varying results after the first procedure?
- Did any of the students have trouble getting results?
- What did their models look like?
- Were you able to get consistent results after the second procedure?

Prompts used across modules

- What adaptations or modifications did you make to the module?
- Did you include any additional content in the module?
- Were there any challenges or obstacles to implementing this module?
- What recommendations do you have for improving the module?

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