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Classrooms as Workplace: "Early Pre-service" STEM Teaching Experience in a University-Based Summer STEM Institute

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ABSTRACT

The focus of study is to examine the impact that The Orange County Teacher Pathway Partnership (OC-TPP) at CSU Fullerton has had on participants' (community college transfer students) skills and experiences gained in each of the program years from years 2015-2018. Students who participated in the STEM Institute gained pre-professional skills and teaching experience through various activities in the program. Students remained on the teacher pathway because the program allowed them to break out of their comfort zones, build social connections, and adjust to various groups of people. Attending the program increased college student confidence in content knowledge and content-based pedagogy, through their university-based experience. In addition, participants gained technical skills in science and teaching through professional exposure

Keyword: Pre-service STEM

At about the time The Center for American Progress released their "America's Leaky Pipeline for Teachers of Color" Report in 2014, the Orange County Teacher Pathway Partnership (OC-TPP) was awarded funding to fix and grow its existing regional level teacher pipeline- and even extend it out to recruit younger (community college) students into it. The OC-TPP, as a University-Community College Partnership program developed out of the work of Science Teacher Education instructors and staff at California State University Fullerton (CSUF), has established a teacher pipeline by building an academic program that would stretch across multiple institutions and would become the pathway towards admission into a teacher education program. From the beginning, the goal of the pathway was to expand the quantity and diversity of the teacher workforce, build a school-to-career bridge and address barriers to employment. Although the pathway represents advancement through the steps toward their academic goals, it also represents a persistence goal, so that students of color do not "leak out of the system" (Amad & Boser, 2014, p. 7) at multiple junctures in the teacher preparation pipeline (Mitchell et al., 2000). The extent to which the OC-TPP has successfully introduced Science Education pedagogy and classroom teaching experience to students at such an early stage of the pipeline, through its STEM Summer Institutes, is the focus of this study.

Recruitment and retention of highly qualified teachers educational leaders concerned that there will be a severe teacher shortage: "the state could easily face `very severe shortages' of teachers...It takes a long time for the pipeline to recover...Prompt action is needed to prepare new teachers and avert a significant loss of educational quality" (Freedberg, 2013, p.11). As economic growth and social well-being have come to depend more on STEM fields, educators need to effectively prepare students to enter and lead in STEM-related industries. A study funded by the National Science Foundation found that many teachers felt unprepared to teach math and science and are not confident that they can provide effective math or science instruction to a diverse group of learners (Epstein & Miller, 2011). Therefore, OC-TPP has worked to change how aspiring teachers feel towards math and science. To this end, the program provided extensive pre-service professional development, work experience, and externship opportunities- emphasizing effective inquiry-based math and science instruction, as well as integrating math and science skills development into the teacher Pathway.

This partnership program also was born out of the well-documented need in the literature of the actual transfer journey of students from the two-year to the four-year institutions- to reach a STEM Teacher Education program. A study by the Carnegie Foundation found that, "The high number of inexperienced teachers in public school classrooms is a largely unrecognized problem that undermines school stability, slows educational reform, and hurts student achievement" (Headden, 2014, p. 18). Math and science classes in high-minority schools are often taught by under-prepared teachers, impacting student achievement (National Science Foundation, 2014; Rice, 2010). The OC-TPP model (a 4 year/ 2-year partnership model) has engaged students in pedagogical training and work experience while they are in community college, preparing them to be effective paraprofessionals in school environments, and provide field experiences in pre-service teaching programs. By the time these future educators earn their credentials and enter the profession, they will have years of experience in working with students, applying reform pedagogical practices, and honing their skills. This type of experience is valuable also for addressing the on-going need of “creating and sustaining effective partnerships between two-year and four-year institutions,” which was one of the greatest challenges, according to the Summit on Community Colleges in the Evolving STEM Education Landscape (National Research Council and National Academy of Engineering, 2012). This partnership also addresses the well-known transition problem students face due to poor articulation between the 2 year and 4-year institutions. According to a recent study, 14% of transfer students had less than 10% of their credits accepted, and only 58% of transfer students had more than 90% of their credits accepted. As expected, as the percentage of credits transferred increased, the likelihood of attaining a bachelor’s degree also increased (Monaghan & Attewell, 2014). Furthermore, co-curricular programming has been known to positively support students’ self-perceptions of competence, and serve as a form of support for transition, persistence, and attainment of a degree, particularly for underrepresented students (Gandara and Maxwell-Jolly, 1999; Hurtado et al., 2009; Mabrouk & Peters, 2000). Another barrier that this program has worked to overcome is the “disjointed and confusing articulation agreements that can negatively impact transfer rates, and in STEM fields specifically, distinguishing between prerequisite courses for STEM majors and those offering technical skills for other majors is confusing” (Tornatzky et al., 2006). Addressing these barriers is a priority in this partnership program because transferring is a formidable barrier to four-year undergraduate completion. Therefore, reducing institutional barriers between two- and four-year colleges is necessary to increase STEM degree attainment rates and path to a career in STEM teaching (Melguizo & Dowd, 2009). Besides addressing negative barriers, this program partnership is built on evidence that STEM-related work experience has related to increased persistence “if the students decide their major coincides with their career interest (Jaeger et al., 2008).

The OC-TPP Program Background

The OC-TPP role in the Pathway is unique because it brings partners together to build out such an early stage of the teacher pipeline- which seldom amounts to more than information sessions on pursuing a teaching career and/or service-learning opportunities working with young children. Typically, it is not until students earn their bachelor's degree and are admitted into a Post-baccalaureate teacher education program that they receive the training and work-based experience needed for the classroom. OC-TPP provides intensive, introductory-level STEM teacher training during the Summer Institute, roughly 3-4 years before students would normally have access to this level of pre-service teacher training. Therefore, it seems the most fitting description of this work with community college students, is to call it, *Early Pre-service*. The partnership structure of the Pathway outlined in Figure 1 (below) specifies the educational progression students make through the partner institutions toward becoming a teacher. The Pathway articulates the CA credentialing program, the unique experiences and expectations students face at each stage, barriers and supports to timely advancement through the stages, and the expanded institutional capacity at key points in the Pathway. Dual enrollment is a key factor for the traditional education Pathway, and articulation agreements were instrumental for a fluid progression from community college to CSUF within the Pathway.

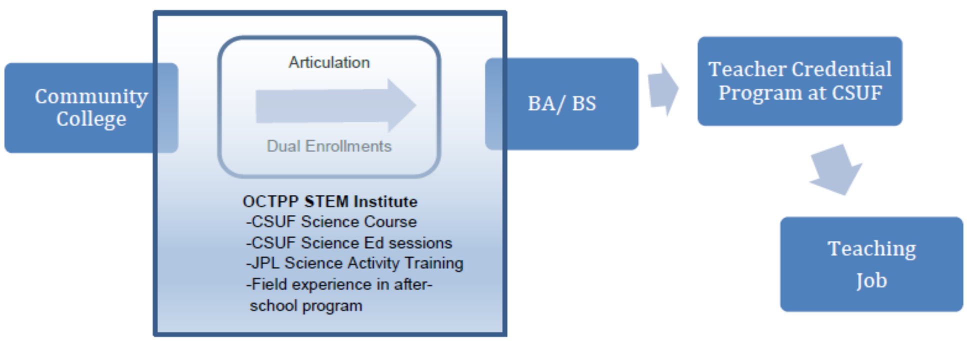

Figure 1. OC-TPP Pathway

What makes OC-TPP possible is the partnership. Since the beginning, Santiago Canyon, Santa Ana, and Fullerton Colleges have partnered with CSUF to build out this Pathway. The three community colleges have a long-standing partnership with California State University, Fullerton's Teacher Education Programs, and have worked with CSUF on curriculum development, articulation, and numerous Pathway and transition projects that have increased student interest and readiness for college pre-service teaching programs. All three community colleges are founding members and co-facilitators of the Regional Teacher Education Council in partnership with CSUF's College of Education.

Additional partnerships with community organizations, including The Jet Propulsion Laboratory (JPL) education division, and Anaheim Achieves/YMCA (AA), have enhanced enrichment activities and experiences for post-secondary pre-service teacher students. They recognize the need for better-prepared teachers in science and math, so they extended their pre-service and in-service curriculum and STEM experiential learning to the project. Anaheim Achieves, a local after-school program tied to YMCA, has played a key role in providing classroom environments for trained certificated teachers to deliver innovative Science lessons for the Enrichment portion of the on-going after-school program schedule. A partnership with CSU Fullerton has been mutually beneficial in preparing future STEM educators in the OC-TPP to work effectively with school-aged children, many of whom are underrepresented and disadvantaged, while also providing our after-school program with trained volunteers to provide our youth with tutoring and mentoring services.

At the foundation of OC-TPP is the deep commitment to work-based learning. Specific to the teaching profession, this means students are introduced to teacher preparation much earlier than usual- before one is admitted into a pre-service, post-baccalaureate teacher credential program. It is, therefore, nothing less than Early Pre-Service learning, and therefore, pathway students, even at the community college level, can connect to the profession well before the typical post-baccalaureate student. It is also through OC-TPP that students may start earning credit towards certificates permitting them to work at an After-School program.

At the Community College Level, the goal is the completion of the Associate Degree and CSU Transfer requirements. CSUF and the three community colleges have a long and successful tradition of collaboration around the transfer and preparation of teachers. The Community Colleges support students in balancing cohort-specific classroom experiences and completing specific courses he/she needs. The educational pathway leads participants to complete the general education and major requirements for the Associate of Arts degree that will lead to transfer to CSUF. All three community colleges on their own have well-established teacher preparation pathways, including AA degrees in Elementary Education (Pre-Professional) that are fully articulated with CSUF and prepare students to enter CSUF as Child Adolescent Studies, Liberal Studies, or Human Services majors. Each student participant has worked extensively with the members of their local community college campus staff to develop and monitor a detailed plan to achieve both their short- and long-term educational goals. Project participants would then be ready to transfer to CSUF within a two-year period, though some may need more time to complete an AA degree and transfer requirements.

Inside the OC-TPP Program

The OC-TPP Summer STEM Institute is designed as an immersive summer program for community college students who spend a summer at the university to get them familiar with the university campus. In particular, students in the Institute:

- Enroll in the General Education Science course at CSUF through dual enrollment, while participating in the STEM Institute at the university.
- Receive training in thematic-based STEM lessons by Science Teacher Education Faculty Member and Education staff from JPL.
- Receive firsthand experiences with effectively working with students one-on-one and in small groups.

The Institute is a 7-week summer program. While many universities offer a summer stem program, very few offer an Institute dedicated to the goal of introducing community college students to STEM education (or teaching). To this end, the Institute delivers a unique, *early pre-service* learning experience that includes, introduction to science pedagogy (that involves problem setting experiences and engineering design) and structured dialogue about high impact practices for tackling college and university academic challenges.

The Institute is structured into four blocks that include the summer Biology/Geology/Chemistry coursework block, Science for Educators, JPL/NASA Problem Setting block, and Project-Based Enactment block. Each of the blocks is described in more detail below:

Science Coursework. Students will enroll in a dual enrollment in CSUF's Science for Educators courses in Biology, Earth Science or Physical Science. Students will be supported through the rigor of these university courses by involved faculty, dedicated tutors and organized study sessions that are part of the institute activities. The Science for Educators courses taught by university faculty in our College of Natural Sciences and Math the students take 4 days a week, 3 hours a day for 7 weeks (what is typically a whole semester long).

Applied Pedagogies in Science. Another component of the STEM Institute, the purpose of the weekly session, led by the CSUF Science Education Faculty member, is to engage Institute students in inquiry-based pedagogical knowledge and skills. Inquiry for the program is defined as a multidisciplinary student lead activity, where students ask driving questions that show critical thinking and application of skills to pursue explanations of phenomena. On a broader level, students are also introduced to basic facets of lesson planning, classroom observation, and assessment strategies.

Project-Based Learning with JPL. Field-Based Practices will be facilitated by the JPL faculty. These were sessions held once a week in the afternoon. Two JPL Education Specialists facilitated the problem setting process for students, using NASA education projects so they could bring field-based problems into the K-12 classroom. Students then designed lessons around these projects while incorporating the knowledge gained from the Science coursework and Applied Pedagogies sessions. Students worked to practice their lessons week-to-week to deliver them to actual elementary school-aged students in the Anaheim Achieves After-school program.

Work-based/ Classroom-Based Teaching Experience. The OC-TPP students delivered their project-based lessons in the field at one of our after-school provider sites- Anaheim YMCA. OC-TPP students taught five prepared lessons from their Applied Pedagogy session, which involved engaging students in small groups or one-on-one while learning through lesson planning and learning to apply classroom management skills. The experience was also designed to help students identify learning goals based on the Next Generation Science Standards. A broad range of activities was then planned, practiced, and then finally implemented.

At the end of this experience, students walk away with experiences that would otherwise await them much later, and with less knowledge, at their early stage, about how to keep advancing toward a career as a fully credentialed teacher.

Method

Central to the research design of this study is our focus on developing a foundational understanding of OC-TPP candidates experiences as part of their engagement and participation in a STEM teacher education program that is distinguished by the vast offering of teacher education experiences, fieldwork opportunities, academic and personal advising services in a supportive educational context. This approach and selection of data sources resemble what is collected and analyzed in the vast majority of STEM Education studies (Brown, 2012). More specifically, such studies in STEM were focused on describing the processes of practicing teachers and the experiences of teachers in professional development programs (Rose, 2007; Brown, 2012). The research focus of this project is three-fold. The research questions driving this study were the following:

1. In what ways did participating in the OC-TPP summer institute impact the participants' understanding of teacher practice as defined by the planning, enactment of a lesson, and interpretation and translation of student learning outcomes.
2. In what ways did the OC-TPP summer institute impact candidates' ability to facilitate learning for elementary children?
3. In what ways did participating in the OC-TPP summer institute mentorship impact the participants' ability to learn teaching?

Data and Instruments

The current study utilized a mixed-methods approach, capturing three years of data from both quantitative and qualitative measures. Students enrolled in TPP Summer STEM Institutes took self-reported surveys and participated in focus groups.

The Institute participants were between the ages of 17-24, who have struggled with multiple at-risk factors, and who had struggled academically in the past. Many of the program students have very limited adult and peer interaction and support, and even less counseling and mentoring.

This study relied on online surveys via Qualtrics, an online-based survey program, which uses both open-ended and closed-ended questions to collect participant survey data. Data collected from surveys include demographic information (e.g., age, gender, race, education level, etc.), participants' interest, interest in STEM education, overall knowledge about careers in education, as well as suggestions for program improvement. Most questions included Likert-scale questions based on a four-point scale, from Strongly Disagree to Strongly Agree.

In addition to collecting survey data, students were interviewed and recorded for a five-minute-long promotional video to share about the quality of their experience in the Summer STEM institute.

Focus groups were also conducted during the 2017 summer programs to capture additional insight into students' experiences and perceptions of the program. Focus groups were conducted for community college students regarding program experience. The focus groups included 4 participants each year and were conducted for community college institutes. Students were asked to discuss what motivated them to join the program, their level of involvement in the program, and how the program has affected their knowledge of STEM teaching. Participants also offered suggestions for program improvement.

The following is a summary of the instruments administered to community college students 2015- 2017.

Table 1

Summary of instruments used by TPP

Summer Year	Program	Pre- and Post-Surveys	Promotional Videos	Pre-Focus Groups	Post-Focus Groups
2015	College	✓	✓		
2016	College	✓	✓		
2017	College	✓		✓	✓

Procedures

Surveys were administered to all students who were enrolled in each of the Summer STEM Institutes during 2015, 2016, and 2017 summers. Surveys and two focus groups were administered to all students after completion of the program.

Analysis Methods

First, quantitative survey data were analyzed first. Descriptive and mean comparison analyses were performed on quantitative data gathered from surveys. The analyses explored frequencies, valid percentages, sample sizes, and score distributions. Graphs were created to visually represent descriptive comparisons between groups and item responses. Tables were also used to help summarize and explain responses.

The analysis of qualitative data included making meaning of interviews and focus groups. Qualitative data collected through focus groups and promotional videos continued to highlight student's positive experiences from participating in the Summer STEM program in the years 2015-2017. The focus group audio recordings and notes were carefully reviewed for emergent themes using an open coding system. This required a review of the audio recordings several times and used interview notes. The analysis process involved looking for patterns, inductively coming to provisional conclusions through direct interpretation and/ or categorical aggregation (Stake,1995). Two general strategies for analyzing the data included: "relying on theoretical propositions and "thinking about rival interpretations" (Yin, 2003, p. 114).

Findings

The following results consist of cumulative data representing an aggregation of findings across all three years (2015, 2016, & 2017) of data. Quantitative survey data were analyzed to complement the findings of the qualitative data, which appear first in Table 2 below. For the quantitative analysis, descriptive and mean comparison analyses were performed on data gathered from pre and post surveys. Table 2 below starts by summarizing the four emergent themes drawn out from qualitative data.

The themes above indicated that the Summer STEM Institute provided a supportive environment for students. Students reported academic, professional, peer, and faculty support as examples of what keeps them on the pathway. Therefore, the findings below are organized according to each of these themes:

Table 2
Emergent Themes: What College Students Gained from Summer STEM Institute

Themes	Descriptions
Science Course engaged students and improved students' content competency	Students were taught by engaged faculty and augmented by dedicated tutors that were part of the institute's support services.
The curriculum introduces skills to prepare students to plan and teach Science Lessons	The curriculum gives students introductory-level content-based pedagogy skills normally introduced in a postbaccalaureate pre-service program.
Students engage in work-based learning by teaching a prepared lesson in a real classroom of actual students	TPP program partnered with the After-School program- which allowed trained TPP students to teach a weekly Science lesson to their students. Through this experience, TPP students gain experience and skills that better qualify them for jobs/internships.
Feedback from experienced teachers aids students' improving their skills	Faculty/staff give students the necessary feedback, which helps their early development as teachers.

Finding 1: Science Course engaged students and improved students' content competency

The TPP students participated in a 7-week daily Summer Science course at CSUF. Students were enrolled in one of three courses: Biology, Chemistry, or Geology. The science course increased participants' learning and understanding of the course content through course components that focused on an activity-based and active learning approach to teach science. No less than 92% of participants reported that lab activities, structured discussions, group work, and active learning in the classroom helped participants have a better understanding of the science content than from the time they started in the summer program (Fig. 2).

Analysis of Focus Group data supported the above findings. While in the program, students were able to observe and identify the ways faculty helped to build their interest in learning science. Students described the teaching strategies the instructors utilized in the program as effective in their learning experience. The feedback from participants illustrated the long-term impact of the program for a student pursuing a career in teaching. One student noted, "Their strategies are amazing and very engaging, and with my professor she knows how to make things fun and knows how to engage us and make us understand with real life experiences and I feel like I can take that into field and for children to understand from their own experience." The students shared an appreciation of the teacher's presentation of the material because it allowed them to enjoy learning about science. Another student added, "he gave us explanations and visuals with his hands and using people to show it that's what I like about him because he explains into different ways of teaching." When instructors were teaching using a strategic method, students were better able to understand the content and helped increase interest in what they were learning.

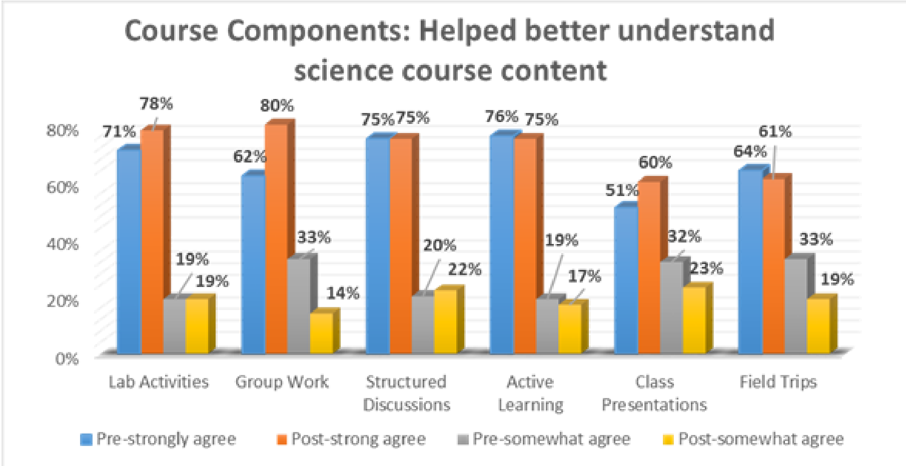

Figure 2. Survey Results on Student Experience with Science Courses

Finding 2: Curriculum introduces skills to prepare students to plan and teach Science Lessons

Intuitively, the numerous benefits of partnering with a Science Education faculty member who also possesses deep expertise in the Next Generation Science Standards seemed like a "win-win." Fortunately, the analysis of both qualitative and quantitative data supported the value this faculty member would bring to the program.

One student explained the benefits of the weekly Applied Pedagogy sessions with the Science Education faculty member, saying: "[the program] helped me gain experience on the field, with lesson planning, classroom management skills, get familiar with being able to teach kids, or deliver lesson plans with other group members." Again, without this program, these community college students probably would not be introduced to such skills and experiences for another 3-4 years (before transferring and then earning their Bachelors' degree and then after being admitted into a postbaccalaureate University-based Teacher Education program. Another student added, "[the program] lets you experience what teaching is about and what tools you need to be a leader too." To support these findings, students attending the 2015 to 2017 Summer STEM Institutes responded to survey questions on knowledge of teaching and classroom management techniques (N=90; see Table 3):

In addition to these benefits, students expressed their gratitude in being able to gain this knowledge as a community college student. They stated, "I acquired so much knowledge on teacher pedagogy, which was awesome because that is something you usually don't learn until your teaching credential, and I was lucky enough to learn that as a community college student." This is an example of how the program supports persistence at an early stage of the teacher pathway; and, at this early stage, are some of the same experiences that post-baccalaureate students would have when admitted into a credential program.

Table 3

Skills and Experiences Gained from Applied Pedagogy Sessions across 2015 and 2017 years of program implementation

I have used the following in my work with students: (1=Never, 5=Always)	Mean (M)	Standard Deviation
Student led activities.	4.04	1.438
Show critical thinking by asking questions.	4.26	.801
Lesson planning.	4.13	.497
Show application of skills to explain phenomena.	4.03	.664
Enact an activity.	4.28	.657
Reflect on teaching outcome and make necessary changes for the next activity	4.22	.627

By participating in the Summer STEM program, students were given a rare and exclusive experience participating in weekly sessions with an educator from JPL. Their expertise from having developed the activities themselves provided a perspective on teaching that included strategies AND preemptively troubleshooting problems that may occur when delivering the lessons. Having been teachers themselves, they also reinforced effective classroom practices. A student shared, “I learned how to teach science lessons that were incorporated from the JPL/NASA program, including how to manage the classroom [while teaching the activity] and also deal with attention-getters.” Students attending the 2015 to 2017 Summer STEM Institutes responded to survey items on their learning from the JPL/NASA sessions (N=90; see Table 4):

Table 4

Benefits Learning from JPL educators across 2015 and 2017 years of program implementation

The following is true for me: (1=Strongly disagree, 5=Strongly agree)	Mean (M)	Standard Deviation
I have learned science concepts through hands-on experience, demonstration, and projects.	4.83	.740
Enacting science-based projects have helped me understand science.	4.79	.983
I have applied and connected science to how it is used in the field.	4.70	.917
I feel prepared to teach science to elementary students.	4.60	.989

Based on these results, the students, on average, strongly agree that their JPL/NASA sessions positively added to their early growth in understanding and applying key concepts in STEM education- from beginning to end of the program.

Finding 3: Professional skills grant students additional opportunities

As an integral part of the OC-TPP STEM Institute experience is for students to train for employment in a specific school-based classroom environment. In the Institute, the required teaching experiences were programmed in as part of the summer schedule of the Anaheim Achieves/ YMCA. Given the specific instruction, training and practice that had occurred in the other parts of the program, it is in this authentic, field-based environment that students gain early experiences in the profession. Although much of students' attention was spent on preparing for delivering instruction effectively, they were also asked to reflect on what they learned through this experience. Table 5 below represents this learning.

Table 5
Growth in Understanding and Applying STEM Education across 2015 and 2017 years of program implementation

Please state your level of confidence for the following questions: (1=Not confident, 4=Very confident)	Mean (M)	Standard Deviation
I have an understanding of basic science concepts.	3.65	1.08
I can integrate my knowledge of science concepts in the real-world.	3.57	.749
I will do well in the Summer STEM Institute science course (Biology, Chemistry, and Geology).	3.44	.464
I can teach basic science concepts.	3.55	.765
I can manage a classroom of elementary students.	3.57	.276

Based on these results, the students, on average, have significantly increased their level of confidence for the following statements after attending the program: I have an understanding of basic science concepts, I can integrate my knowledge of science concepts in the real world, I can teach basic science concepts, and I can manage a classroom of elementary students, $p<.05$. However, there was no significant difference in the statement I will do well in the Summer STEM Institute science course Biology, Chemistry, Geology), before and after attending the program.

The other participants who were unsure of a teaching career shared, "This program [TPP] helped me realize that I do want to pursue a career in education." One of the students who reported wanting a teaching career stated, "[the TPP program] helped me open my eyes, give me the experience I needed in order to pursue other advances in the career." A student also shared an incident during the program that impacted her decision to become a teacher. They shared, "These two little girls came up to me, and they were like…we are going to miss you and that was the moment where I was like… yeah…no…I'm meant to do this…it made me more excited for the future." In joining the program, not only have students been exposed to teaching, but they were given a chance to reflect on their professional goals.

Finding 4: Feedback from experienced teachers aids students' improving their skills

Not only did OC-TPP students gain experience in the profession. They also received supervised feedback on their teaching performances. In the last two years of the program, in-service teachers were hired to observe and provide valuable, coaching-style feedback to participants. The students found criticism and overall feedback to be beneficial for their learning development during the program. A student shared, "[I] learned about leadership during the lesson. As a group, we identified what each member needed to work on." Additionally, a student expressed the feedback to be helpful as they stated, "there was always someone there who has done the activities that can direct me to the right path and give me constructive criticism, which was really helpful." This feedback allowed students to discover their areas of improvement, which further supported their learning.

To support these findings, students during the 2015 to 2017 Summer STEM Institutes responded to fieldwork observation feedback after the completion of the program (Post: N=90; see Table 6):

Table 6
Benefits of Master Teachers' Observation Feedback on Lessons across 2015 and 2017 years of program implementation

Questions (1=Strongly disagree, 5=Strongly agree)	Mean (M)	Standard Deviation
The Master Teachers provided meaningful feedback about my teaching.	4.20	1.326
The feedback provided helped me improve my lesson planning every week.	4.33	1.161
The feedback provided allowed me to better prepared to facilitate an activity to elementary students.	4.34	1.210
The feedback provided helped me strengthen my classroom management skills.	4.37	1.166
The feedback provided will help me in my future work with students.	4.43	1.142

Based on these results, the students, on average, agree (4=agree) that Master Teachers provided meaningful feedback, feedback provided helped improve lesson planning, feedback provided allowed better preparation to facilitate activities to elementary students, feedback provided helped strengthen my classroom management skills, feedback provided will help future work with students.

Conclusions and Implications

After several years of implementation, the Teacher Partnership Pathways (TPP) has established an early pre-service teacher education model introducing underrepresented students to future careers in Science, Technology, Engineering, and Math (STEM) education.

Throughout the STEM Institute, students gained pre-professional skills and teaching experience through various activities in the program. The program also implemented visits to, and lessons from, the Jet Propulsion Laboratory (JPL). Through the years of offering the STEM summer Institutes, college students reported that JPL helped them learn numerous science concepts and how to teach science to elementary school children. Attending the program increased college student confidence in demonstrating science projects. In addition, college students gained professional, personal, and academic support from the program. They also report their ability to speak to school personnel, the benefits of tutoring, resume building, and how this experience has supported their futures. The community college students showed positive responses and reported being comfortable and less prepared after attending the institute.

To date, the educational pathway/timeline is not obvious to an incoming student, particularly transfer students, because many California universities do not often provide opportunities for early entry into a teacher pathway at a pre-undergraduate, pre-transfer level. In fact, many California universities do not offer undergraduate degrees in education because students must prove subject matter competency in order to enter a teacher preparation program, thus majoring in the subject they wish to teach is recommended. Once students do find the appropriate pathway, they are often not connected to schools or colleges of education until their senior year of college, when they begin taking pre-requisite courses for the teacher preparation programs. If students are not able to find a pathway to teaching earlier in their educational experiences, they may spend more time completing preparation programs and, worse case, be more likely to change their career goals altogether.

The OC-TPP program has given students the opportunity to explore the teaching profession and pursue an undergraduate degree by way of early exposure to teacher preparation curriculum, fieldwork experiences in public P-12 schools, and mentorship from experienced teachers. This program was designed to prepare students for a mindset to be college-ready, but also career-ready, which was aimed at increasing higher transfer rates, degree completion rates, and enrollment into teacher preparation programs among participants.

We believe that developing “locally-grown” educators will benefit generations to come as our teachers tend to originate from and stay in the communities in our region, those we are most dedicated to serve. Building upon partnerships between CSUF, Santiago Canyon College, Santa Ana College, Fullerton College, and P-12 school districts with a large percentage of underrepresented students allows us to encourage students who come from diverse backgrounds to pursue a career in teaching and provides the supports needed to retain them.

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Integrating Literacy into STEM Education: Changing Teachers' Dispositions and Classroom Practice

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ABSTRACT

In this paper, the results of a study of teachers' dispositions and classroom practices regarding literacy integration into STEM courses are presented. The Connection Core Concepts (CCI) program, developed through Mathematics and Science Partnership (MSP) grant funds, was designed to support the integration of content across subject areas. Literacy is one of the emphases in Integrated STEM to enhance teacher content knowledge and increase student success. Research data were gathered from 30 teacher participants from Grades 5–8 through surveys, observations and interviews. The results indicated that there were positive changes in teacher perceptions as well as classroom practices in regard to integrating literacy into STEM.

Keyword: STEM; literacy; Integration; Dispositions; Practices

Background

The authors of this paper were involved in a three-year Math and Science Partnership (MSP) grant program to provide teacher professional development that was focused on improving STEM teachers' content knowledge and providing tools for them to implement the new state science standards. Each year a specific science content was addressed: Physical Science in year 1, Earth and Space Science in year 2, and Life Science in year 3. A team of university faculty members representing various disciplines collaborated closely to provide training in current science content knowledge and best practices in Integrated STEM education. One of the key areas of the training was literacy integration. A three-year training plan that included the integration of reading comprehension strategies, vocabulary/concept development strategies and writing strategies into life science, physical science, earth science, math, and some other STEM classes was designed and implemented. A statistical analysis of data collected through pre- and post-tests, a minimum of two classroom observations, and interviews of a random sample of participants was conducted to evaluate the effectiveness of the program.

The project was housed in the Institute for STEM Professional Development and Education Research (STEM Institute) at a public university in the southwest United States. In collaboration with a neighboring Educational Cooperative, the STEM Institute created an ongoing partnership between high-need school districts and STEM faculty from the College of Education and the College of Natural Sciences and Mathematics. Science initiatives were developed to enhance learning outcomes that support the implementation of new state standards which are based on Next Generation Science Standards (NGSS). The initiatives included multimodal instructional models that support multiple forms of assessment and provided a long-term and sustainable high-quality professional development opportunity for a minimum of 100 contact hours during each year of the project. This included a two-week summer institute, four Saturday sessions during the academic year, and two classroom observations.

The project focused on the improvement of science instruction in grades 5-7 by integrating mathematics, literacy, and technology to enhance teacher content knowledge and teaching skills that prepare students for success. To better understand the participating teachers' dispositions and classroom practice and the impact of training, questionnaires were developed and administered each year. In this paper, the authors intend to report the findings of the pre- and post-training surveys to assess the impact of the training. The results from this study were used to evaluate and adjust the training. The authors hoped that the data may also provide literature in the area of Integrated STEM education and specifically literacy integration into STEM subjects.

Literature Review

According to Brown (2012), and Mizell & Brown (2016), based on their analysis of the articles published in eight major STEM-focused journals from 2007 to 2015, Integrated STEM was the most-researched theme in STEM research. This integration was mainly an effort to address the separation of the STEM disciplinary areas, as Moore and Smith (2014) state, "[I]n general, integrated STEM education is an effort to combine the four disciplines of science, technology, engineering, and mathematics into one class, unit, or lesson that is based on connections among these disciplines and real-world problems. More specifically, STEM integration refers to students participating in engineering design as a means to develop relevant technologies that require meaningful learning through integration and application of mathematics and/or science." (p. 5) However, some researchers and educators call for the integration of art, English language arts, social studies, and other subject areas to address the disconnected traditional STEM education model (Gess, 2017; Sanders, 2009). Given the importance of literacy in learning and communicating content knowledge, STEM researchers and educators should consider including this important piece in the puzzle.

Historically, one area of research in disciplinary literacy was teachers' beliefs about integrating literacy into their respective content areas and their classroom practices. The traditional view on the issue was that content area teachers were only responsible for teaching the content, not reading or writing (Ratekin et al., 1985; Siebert & Jo Draper, 2008; Stewart & O'Brien, 1989). The content area teachers expected their students to be able to read and write when they came to their classrooms. Yet, current educational standards such as Common Core State Standards (CCSS) and

Next Generation Science Standards (NGSS) clearly require the teaching of literacy in content areas as evidenced in the following standards: CCSS Literacy Standards for History and Social Studies, Literacy Standards for Science and Technical Subjects, and the reading and writing standards in NGSS. Hence, content area and STEM teachers are mandated to change their dispositions and classroom practice to meet these teaching standards. In this new era of standards-driven education, do STEM teachers embrace this change? Have they adopted new teaching practices to include reading and writing in content area learning? Will this training lead to any change in their dispositions and classroom practice? The survey research would help the authors better understand the above questions.

The limited research on this topic seems to have yielded inconsistent findings. For example, in a year-long literacy professional development project, Cantrell et al. (2009) conducted a pre- and post-survey on middle and high school content area teachers' beliefs about literacy integration and found that most content area teachers' dispositions turned more positive through the training. They reported that most teachers believed that literacy was integral to their content areas, and they viewed themselves as both literacy teachers and content teachers. Although the teachers admitted that they encountered a number of barriers during the initial phases of implementing literacy strategies, they claimed that professional development with coaching and collaboration changed their efficacy and classroom practice. Huysman (2012) confirmed this finding on teachers' attitude change through professional development for high school content area teachers.

Edwards et al. (2015) compared the dispositions and classroom practices pertaining to literacy instruction in STEM classes between those who received literacy training and those who did not. They found no differences between the two groups. In terms of STEM teachers' competence to integrate literacy, research shows consistent results in that the teachers may be well trained in their respective content areas, but lack the knowledge and skills to incorporate literacy into their content area instructions (D'Arcangelo, 2002; Vacca, 2002). Fisher and Frey (2008) concluded that content area teachers know relatively little about vocabulary instruction, one of the key instructional areas in content learning. Research suggests that professional development that is focused on instructional strategies will produce a positive impact on student achievement. For example, Falk-Ross & Evans (2014) found that a teacher professional development training on integrating vocabulary strategies into content areas improved student reading comprehension, vocabulary use, and overall student achievement.

The authors of this study believe that in order to meet the new educational standards, it is imperative that STEM teachers possess a positive disposition regarding literacy integration and know how to implement literacy strategies in content area instruction. This study aimed to investigate the impact of literacy integration training on teachers' beliefs and practices regarding literacy integration into their STEM classes.

Method

Participants

The participants involved in the three-year study were Grades 5-8 public school teachers in a southwestern state in the US. A cohort of 30 teachers were recruited in the first year of the project.

To ensure the effectiveness of the professional development training, the same cohort of teachers were required to participate in all three years of the project. If any participants discontinued due to professional or health reasons, they were replaced by new recruits with a similar background. Most of the teachers were from small rural school districts and were teaching multiple STEM content areas such as life science, physical science, earth science, and mathematics. Some of them were self-contained special education teachers. Teaching experience ranged from one to twenty years, with an average of 8.4 years. There were three male and 27 female teachers. Of all the teachers in the study, 89% were Caucasian and 11% were African American.

Procedures

In order to measure the impact of professional development training on participating teachers' beliefs and classroom practices, the research team constructed a 20-item Likert scale questionnaire and conducted two classroom observations. Another set of questions were included to collect the demographic information. The questionnaire was reviewed by two experts in educational research and tested in a small group of undergraduate students. The items were then revised based on the feedback from the experts and the analysis of the responses from the pilot group to ensure validity. The twenty questions were categorized into three groups: one set to probe the participants' perceptions (two about literacy integration, two about their role and responsibility, and two about their students' ability), one set to measure their knowledge and skills in regard to literacy integration (nine questions), and one set to examine their actual classroom practice (five questions). More specifically, seven questions in the questionnaire were about reading, seven about writing, three about vocabulary instruction, two about the availability of trade books for content area supplement, and one about grouping strategies. Questions range from their beliefs about the importance of involving students in reading and writing in STEM classes, to their perceptions of their role and responsibilities in utilizing reading and writing strategies to teach STEM content, to their beliefs about their classroom practices regarding literacy integration (reading, writing, and vocabulary).

The questionnaire was administered at the beginning of the first-year training as a pre-assessment and at the end of the year as a post-assessment. In the pre-assessment, out of the thirty participants, 22 returned valid responses, which were included in the analysis. In the post-assessment, 25 valid responses were returned and included in the analysis. Some demographic information such as the grade level the participants teach, the content area(s) they teach, and their years of teaching experience was also collected and examined.

The Reformed Teaching Observation Tool (RTOP, Pilburn & Sawada, 2000) was used for classroom observations. To establish baseline teaching practices regarding pedagogy and content, STEM faculty visited the classrooms of the participating teachers during the fall semester of the first year of the program and in the spring of the last year. Developed as an observational tool to measure reformed teaching, or teaching that shifts from the traditional teacher-centered classroom to a learner-centered classroom that is collaborative, integrated, and activity-based, the RTOP is comprised of 25 items across three subsets: Lesson Design and Implementation (5), Content (10), and Classroom Culture (10). Sample items from the three subscales are, "In this lesson, student exploration preceded formal presentation," "The lesson promoted strongly coherent conceptual understanding," and "There was a climate of respect for what others had to say." Observers rate teachers on each item using a five-point scale of 0 to 4 with anchors of Never Occurred and Very Descriptive resulting in possible RTOP scores ranging from 0 to 100. Previous studies of score reliabilities reported inter-rater reliability estimates ranging from .90 to .95 for the total score and .67 - .95 for subset scores (Piburn & Sawada, 2000). Piburn and Sawada (2000) provided a discussion of face, construct, and predictive validity and concluded that, "Analysis of the RTOP suggests that it is largely a uni-factorial instrument that taps a single construct of inquiry… the instrument seems amply able to measure what it purports to measure regarding reformed teaching" (p.27).

The research questions the current study intended to answer include the following:

1. Will the training impact the participants' beliefs about the importance of integrating literacy into STEM classes and their responsibilities to integrate literacy?
2. Will the training impact the participants' beliefs about their knowledge and skills in integrating literacy into STEM classes?
3. Will the training impact the participants' classroom practice?

Results

As discussed previously, two questions were about the participants' perception of integrating literacy into STEM classes. They were asked if integrating reading and writing is important in STEM instruction. In the pre-assessment, four participants chose "Strongly Disagree" on both reading and writing to indicate they do not believe that it is important to integrate literacy into STEM classes. No one chose "Disagree" on either reading or writing. Four chose "Agree" on reading and three chose "Agree" on writing, and 14 chose "Strongly Agree" on reading and 15 chose "Strongly Agree" on writing. On the post-assessment, one participant chose "Strongly Disagree" on both reading and writing. No one chose "Disagree" on either reading or writing. Three chose "Agree" on reading and five chose "Agree" on writing, 21 chose "Strongly Agree" on reading and 19 chose "Strongly Agree" on writing. To summarize, on the importance of integrating reading, 18 chose "Agree" or "Strongly Agree" before the training and 24 chose "Agree" or "Strongly Agree" after the training. On the importance of integrating writing, 18 chose "Agree" or "Strongly Agree" before the training and 24 chose "Agree" or "Strongly Agree" after the training.

As the figure shows, after training, there was a 14% increase (82 to 96) in the number of participants who believe it is important ("Agree" or "Strongly Agree") to integrate reading and writing into STEM classes. It should also be noted that 18% of the participants chose "Strongly Disagree" that reading or writing is important in STEM learning.

On the two questions that asked if they believe that they have the responsibility to integrate reading and writing into STEM classes, in the pre-assessment, three participants chose "Strongly Disagree" on reading and two chose "Strongly Disagree" on writing. One participant chose "Neutral" on both reading and writing, five chose "Agree" on both reading and writing, and thirteen chose "Strongly Agree" on both reading and writing. In the post-assessment, no one chose "Strongly Disagree" or "Disagree" on either reading or writing. One participant chose "Neutral" on both reading and writing, five chose "Agree" on both reading and writing, and 19 chose "Strongly Agree" on both reading and writing. In summary, before the training, 18 participants chose "Agree" or "Strongly Agree" that it is their responsibility to integrate reading and writing into STEM areas. After the training, 24 participants chose "Agree" or "Strongly Agree" that it is their responsibility to integrate reading and writing into STEM classes.

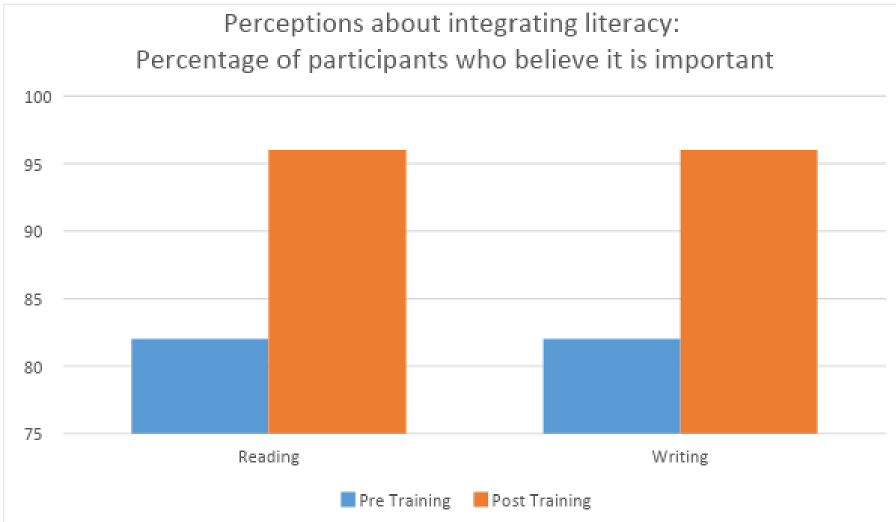

Figure 1. Findings on perceptions about the importance of integrating reading and writing

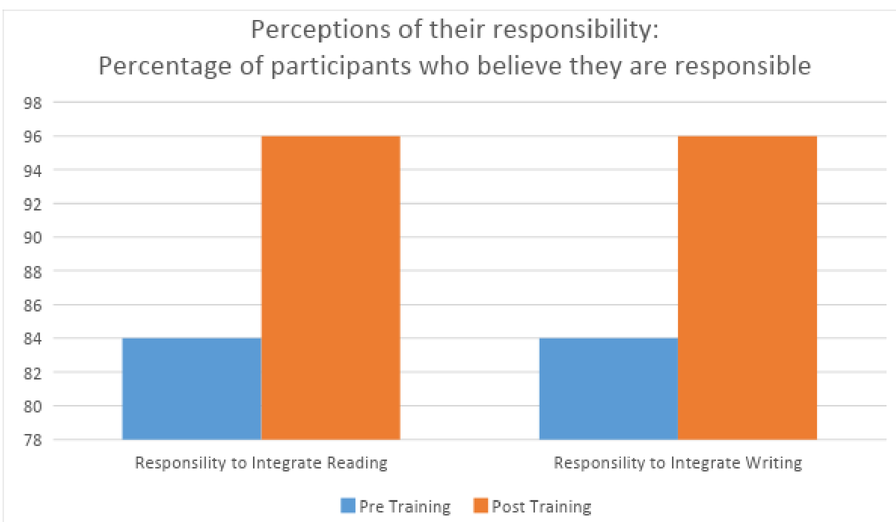

Figure 2. Findings on participants' beliefs about their responsibility to integrate literacy

According to the above data, in terms of the participants' perceptions of their responsibility in integrating literacy, there was a 12% increase on both reading and writing. On these two questions, no participants chose "Strongly Disagree" or "Disagree."

On the last set of questions that examine the perception of change in classroom practice, it is a slightly different scenario. In the area of reading, there was a 24% increase in the number of teachers who believed that they regularly involve students in reading STEM materials after the training. In writing, 16% more teachers believed they regularly involve students in writing in STEM classes. After the training, 25% more teachers regularly taught vocabulary in STEM classes. Data indicates that the training changed many teachers' classroom practice and 25% more teachers incorporated reading, writing, and vocabulary in STEM subjects.

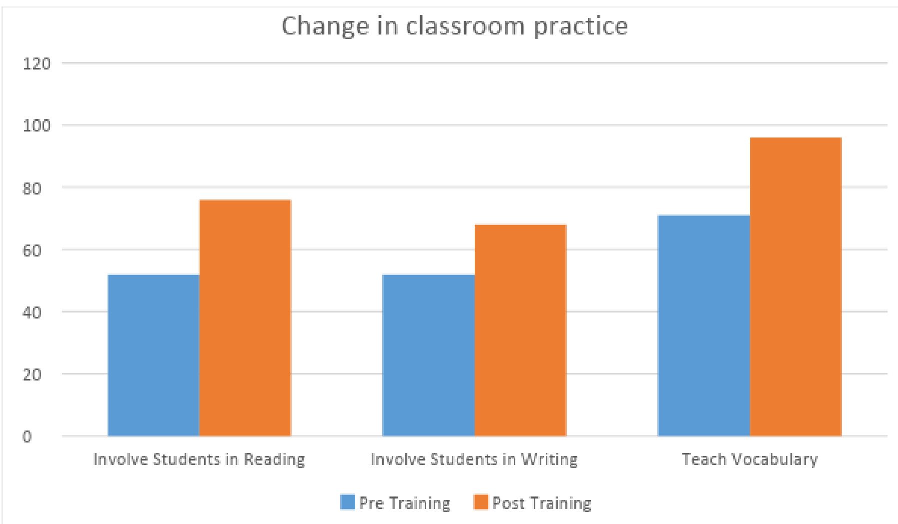

Figure 3. Findings on beliefs about teaching practice

To measure the teacher implementation throughout the 3-year grant period, the first RTOP observation scores from year 1 were compared (as a baseline measure) to the last observation scores from year 3, providing a measure of change over time. An Independent Samples T Test was conducted on each of the three subscales of Lesson Design, Content Total, and Classroom Culture. Results on the Lesson Design Total subscale scores showed a statistically significant effect when comparing the two time periods (year 1 M=18.32, SD 5.91; year 3 M=15.04, SD = 2.46; t(32.63)= 2.54, p= .02). This indicates that over the three years of the professional development, teachers implemented significantly less of these elements into their practice. Results on the Content Total subscale scores show a statistically significant effect when comparing the two time periods (year 1 M=21.48, SD 4.25; year 3 M=34.22, SD = 3.44; t(46)= -11.35, p= .000). The data shows that over the three years of the professional development, teachers implemented significantly more of the elements into their classroom practice. Results on the Classroom Culture Total subscale scores showed a statistically significant effect when comparing the two time periods (year 1 M=24.32, SD 6.08; year 3 M=33.87, SD = 3.01; $t(35.69) = -6.98$, $p = .000$). This indicates that over the three years of the professional development, teachers implemented significantly more of the elements into their classroom practice.

Discussion and Implications

Integrating literacy into STEM courses is crucial for students to succeed in those areas because students have to read and write in all content areas to learn and communicate. STEM teachers' beliefs about literacy integration have profound impact on whether the teachers incorporate vocabulary, reading, and writing activities in the content areas. It is important that teachers have positive dispositions regarding literacy integration and the knowledge and skills to do so.

This research intended to determine the impact of training on teacher perceptions and classroom practice in integrating literacy into STEM classes. Results suggest that the training had a positive impact on STEM teachers' dispositions as well as their classroom practice. There was a 14 % increase in the number of participants who believed it was important to integrate reading and writing into STEM subjects and 12% increase in the perception of personal responsibility to do so. A higher percentage of participants changed classroom practices as a result of the training, with about 25% indicating that they incorporated the reading and vocabulary strategies and 16% incorporated the writing strategies they learned in the training. It should be noted that 18% of the participants "Strongly Disagree" that reading or writing is important in STEM learning.

Classroom observations of the year three showed a significant increase in the quality of literacy integration in science classes as compared to year 1. Before the training, science teachers used definitions of the vocabulary words, note-taking, bell ringers, and lab notebooks while the mathematics teachers used open response questions, explaining the steps used in solving the problems, and rewriting the word problem in their own words. However, the observation after the training showed that teachers used several other strategies in their classes. For example, a science teacher had students make a list of names of muscles and bones and classify them based on their understanding of common characteristics. Students of another teacher started a lab by looking at the weather readings in the newspaper, did a close reading of an article, and identified the author's purpose and the central idea. Strategies such as compare and contrast and students researching a disease of their choice of the circulatory system using primary sources and creating a Power-Point slide to share with their class were also observed.

Participants who had been in the professional development program for all three years were asked to interview in year 3 to ascertain overall impact of the professional development. Four people volunteered to speak to the evaluator. All participants in the professional development were administered the exit survey. There was a total of 29 survey responses. The exit survey showed that 79.5% of respondents indicated that they were either satisfied or extremely satisfied with the professional development training. The qualitative portion of the survey and the interviews triangulated with two respondents reporting that they thought some of the content was outside their area of expertise and some of the content was too complex to assimilate in the time given for the lesson. Three respondents did not find the extra articles given to them to read valuable.

The positive impact of the professional development training can be attributed to the teamwork of university faculty to the intentional pairing of literacy strategies to the science topic in each module. By incorporating a balanced literacy approach into each science concept that was addressed, participating teachers were engaged in an authentic science experiment and content literacy strategies to make meaning of the science concepts rather than take meaning from established resources. In other words, the integration of science and literacy instruction helped teachers contextualize their scientific observations.

Although there were some inherent limitations associated with survey research, the training led to a positive impact on teacher dispositions and classroom practices.

According to the 2010 National Survey on STEM Education, one of the top challenges in STEM Education is insufficient teacher professional development (National Survey on STEM Education, 2010). In order for STEM teachers to change their attitudes and classroom practice regarding literacy integration, more effective professional development should be provided, as found in this three-year investigation.

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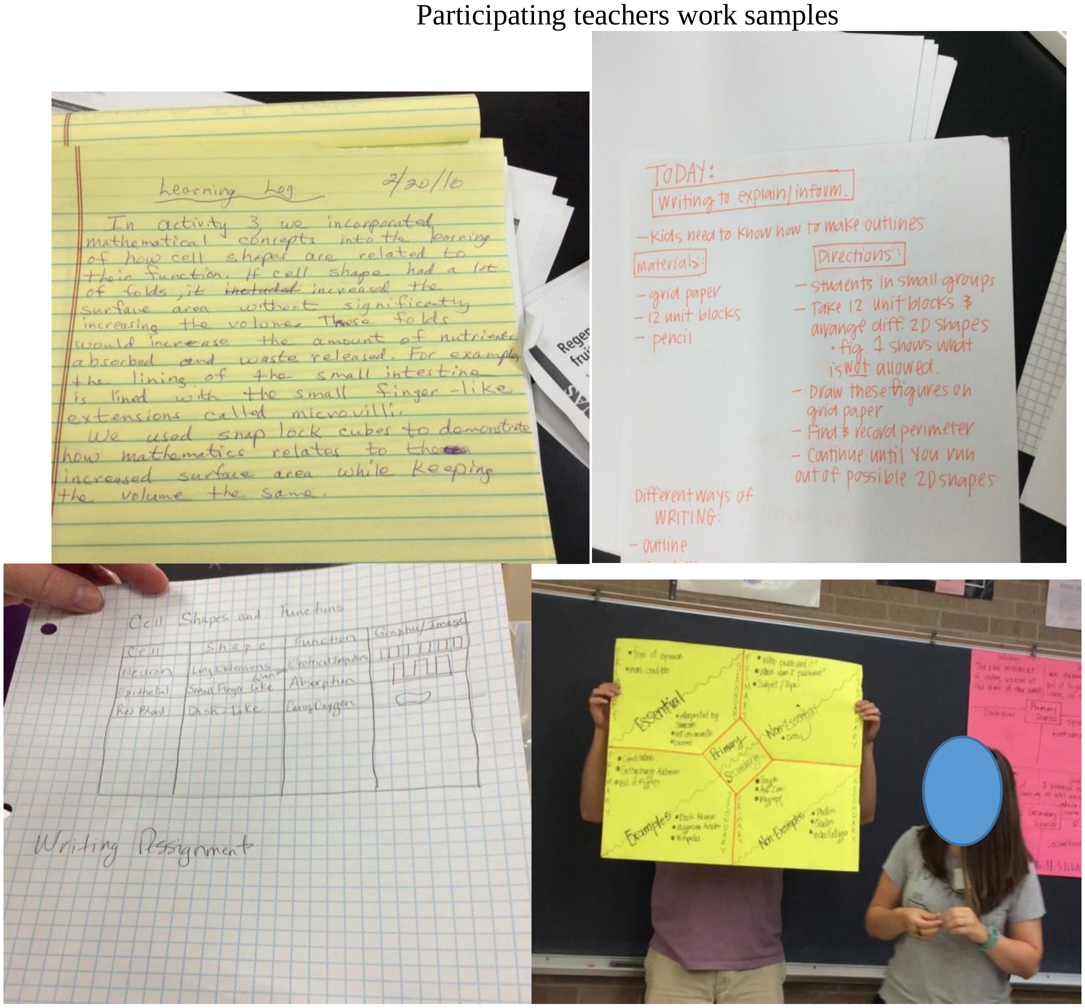
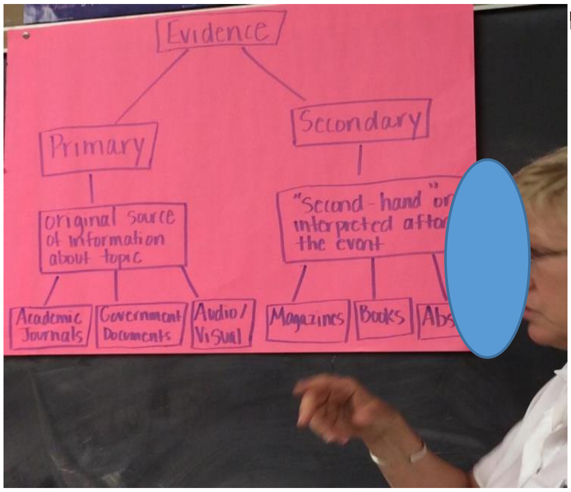
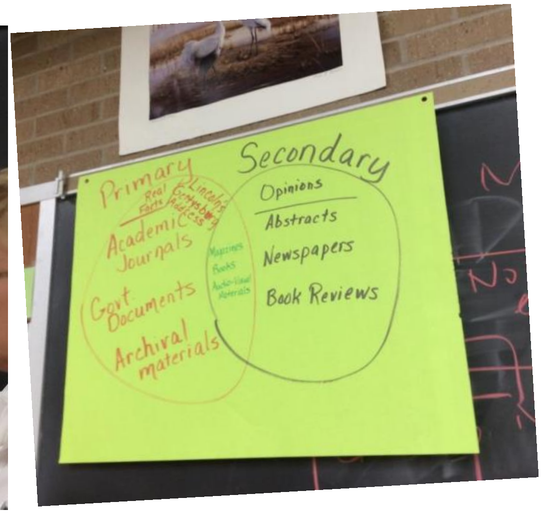
Appendix

Participating teachers work samples







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Nature of Problem-Solving Skills for 21st Century STEM Learners: What Teachers Need to Know

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ABSTRACT

Since the emergence of the fourth industrial revolution which calls for a new model of learning for the twenty-first century learners, it has been argued that the nature of problems that learners must solve in science, technology, engineering and mathematics (STEM) must also be transformed to enable new forms of learning skills that are needed to tackle complex global challenges. However, the question of how best to teach these skills purposefully and explicitly is largely overlooked. STEM education reformers recognize that the lecture method or traditional method of teaching is highly ineffective for teaching twenty-first century competencies and skills that learners need to develop, yet widespread use of this approach continues. In today's world, we need STEM graduates who are more sophisticated in understanding the uncertainty of knowledge through quasi-reflective thinking when there is uncertainty about a solution to a problem. For this to happen, STEM learners need skills such as critical thinking, decision-making, innovation, the ability to communicate new knowledge effectively, and the ability to solve various kinds of problems through negotiation and collaboration, all of which present a corpus of knowledge to be constructed and mastered in a learner-driven pedagogy. Therefore, rethinking the kind of problem-solving skills we teach twenty-first century learners is as crucial as identifying a suitable instructional model. This paper demonstrates how the domain of ill-structured problems-based learning may contribute to the development and mastery of twenty-first century competencies and skills and advance the quality of learning through the argumentation model.

Keywords: Cognition; arguments; STEM; teachers; twenty-first century learners; ill-structured problem solving; skills

The world of science, technology, engineering and mathematics (STEM) education is in a state of flux. New types of jobs, knowledge, and skills are emerging, requiring future STEM graduates to be well equipped to meet the need of the expansion requirements of today's workforce. STEM teacher education must keep abreast of the macro and dynamic changes in the type of knowledge and skills required of STEM graduates. However, a STEM workforce is needed to solve many of the world's social, economic, and environmental problems (National Research Council, [NRC], 2011; UNESCO, 2012). From a teaching perspective, the focus on the skills required for a knowledge-based society (often referred to as twenty-first century skills) raises questions about the nature of problem-solving skills we teach in STEM fields. What alternatives are there for developing twenty-first century STEM learners with the knowledge and skills needed to confront ever-expanding global challenges? Thus, STEM teacher education is faced with a massive challenge of what needs to change. This paper provides insights and suggestions of the kind of problem-based learning and projects STEM teachers need to know that may offer opportunities for their learners to practice and apply knowledge resources in a variety of contexts. This includes relevant examples of real-life problems (see ISP#1 and Figure 2) that can help learners to engage in epistemic cognition, examine multiple solutions, make and defend judgments, and communicate new knowledge. Prior research suggests that some forms of pedagogy are consistently more successful than others in helping learners acquire a deeper understanding of twenty-first century skills (Netwong, 2018; NRC, 2011; Slough & Chamblee, 2017). On this point, this paper also shows how the argumentation model can be used to provide learning situations that encourage critical thinking and problem-solving skills.

One important aspect of STEM teacher education is to equip learners to become competent problem solvers because of the dynamics of the job environments in which they will find themselves in the future. Literature on this topic offers compelling arguments for transforming the nature of problems that learners solve in STEM fields to better support the acquisition of twenty-first century skills (Jamaludin & Hung, 2017; Netwong, 2018; NRC, 2012). Despite this, little emphasis is laid on teaching the skills and understanding involved in achieving these objectives. In many countries, STEM teaching has been mainly driven by tradition-led teaching approaches where textbooks are sometimes the go-between the teacher and the learners (NRC, 2011; UNESCO & UNICEF, 2013a). However, textbook problems are well structured – even those that invoke a supposed real-world context are not as messy as a learner's real life often is. Textbook problems are limited in their ability to provide opportunities to practise important aspects of the twenty-first century competencies and skills desperately needed to confront persistent global challenges (King & Kitchener, 2004). Besides, many problems confronting us in this twenty-first century are not well structured; most have no clear answers or solutions.

Spector and Park (2012) have listed some interesting examples of ISPs that can be found in nearly every aspect of life as well as in STEM subject domain, they include: (i) the design of a bridge to span a particular body of water, (ii) determining how best to treat a patient suffering from multiple chronic illnesses, (iii) finding the fault or faults in an electronic circuit that fails intermittently, (iv) the development of an economic policy to resolve a persistent budget deficit, and (v) planning a large social event. Certainly, ill-structured problem (ISP) solving is a prominent example of a twenty-first century skill, because the current and future global problems, as well as problems in our daily lives, are typically ill-structured. Therefore, the inclusion of essential twenty-first century skills, such as learning how to solve difficult ill-structured problems and learning how to collaborate, can help STEM learners to address enduring or emerging issues confronting them (Facer, 2012; Jamaludin & Hung, 2017). If the twenty-first century learners' competencies and skills are to be properly instilled, we must clearly answer questions about the amount, appropriateness, and relevance of the nature of the problems to which we expose them. More will be said about this in the succeeding sections.

Why Should We Engage the 21st Century Learners to Ill-structured Problem-based Learning?

Real-world experience shows that many problems that learners encounter in their everyday life are ill-structured. Many teachers probably have seen their learners wrestling with issues of finding methods for resolving perplexity where they must make and defend judgements between evidence and a point of view, and how to evaluate such evidence on different sides of issues. As it is in real life, ISPs often possess either multiple or no clear solutions, and because of this, we say they are ill-structured (King & Kitchener, 2004). According to Jonassen and Hung (2008), the complexity of an ISP can be determined by four aspects: (i) the breadth of knowledge required to resolve it, (ii) the difficulty level of the major concepts in the problem, (iii) the intricacy of problem-solution procedures, and (iv) the relational complexity among major concepts in the problem. A problem whose structure accompanies all these kinds of descriptions is characterized as an ill-structured problem (ISP). Normatively, ISPs present a degree of uncertainty about concepts, rules and principles that might be necessary for proposing solutions (Jonassen, 2011a; Shekoyan & Etkina, 2007; Voss, 2006). It surely must follow that engaging STEM learners in ISP solving is important because we all need ill-structured problem-solving skills in order to cope with everyday life. Many researchers view ISP solving as a lifelong learning skill that we need to teach the twenty-first century learners (Facer, 2012; Jamaludin & Hung, 2017; King & Kitchener, 2004; NRC, 2012). To achieve this goal, STEM teachers need to ensure that ill-structured problem-based learning is meaningful, worthwhile and feasible, because a lack of relevance leads to a lack of motivation, which ultimately results in decreased levels of learning (Saavedra & Opfer, 2012).

Ill-structured Problem-based Learning and Project: Teacher's Role

What ultimately makes ISP-based learning and projects meaningful? With ISP-based learning and projects, learners learn by designing and constructing actual solutions to real-life problems (Trilling & Fadel, 2009), carry out detailed research projects, solve various kinds of problems as they arise, make and defend judgements in the face of complexity and uncertainty (King & Kitchener, 2004), and communicate new knowledge that has genuine value for them personally and their communities (Barron & Darling-Hammond, 2008). For this to work well, teachers must design curricula activities that match the interests and the needs of their learners (Barkley et al., 2014). Research by Barron and Darling-Hammond (2008) shows that deeper learning takes place when learners can apply classroom-gathered knowledge to real-world problems and take part in projects that require sustained engagement and collaboration (see Figure 2 and ISP#1). By virtue of their nature, addressing ISP-based learning and projects require judgements, planning, and the use of strategies and the implementation of previously learned skill repertoires (King & Kitchener, 2004). Therefore, it should be noted that completing such activities may not easily fit into the standard '50-minute classroom period', so alternative scheduling should be considered (Trilling & Fadel, 2009, p. 114-115). Further to this, addressing ISP helps develop inquiry skills among learners as they become researchers, seeking out and evaluating new information, collaborating with their peers to tackle problems, and revising existing knowledge (Facer, 2012). ISP-based learning can also help to enhance learners' interest in learning, develop in them a strong knowledge base in the relevant disciplines, and strengthen their integrative learning and application of the essential skills and qualities required in the twenty-first century.

Given the importance of fostering twenty-first century competencies and skills through ISP-based learning and projects, it may not be important to continue teaching only well-structured problems (WSPs) to learners in STEM fields, especially at high school, college and university levels. The point is that the condition of a WSP is invariably satisfied by a given solution, which leaves no room for alternatives. Very often a solution obtained from solving a WSP is considered in isolation from the others as it serves an end to its confined computation. This does not imply that all WSPs within the defined domain can be solved with only reasonable amounts of computation. Some are solvable in principle; many may require immense numbers of applications of operators and tests for their solution, so that the total amount of computation required may be impractical (Jonassen & Hung, 2008; Simon, 1973). By contrast, ISPs are characterized indifferently when solving them. In most cases, the goal is vaguely stated, and requires analysis and refinement in order to make the particular issue tractable (Voss, 2006). In this connection, teachers should choose ISPs most suited to the needs and interests of learners to help them to develop and apply generic skills (e.g. critical thinking and collaboration skills, creativity, originality, strategizing, communication), and subject-specific skills. The ability to develop these skills for use in solving ISPs is something that some learners may find easy to develop, while others may not. Likewise, because of personal difference, a concept explained in one way may be grasped by some learners while it may puzzle others.

Teachers who are concerned about the ISP solving ability of their learners should realize that they can make a difference. For the ultimate benefits of learners, it is good to establish very simple steps on how to solve ISPs. The learners' curiosity is at first qualitative; let that be whetted first, and then turned into a quantitative direction gradually. Depending on the age group of learners, the traditional role of the teacher as dispenser of facts and as the source of knowledge is only a small part of the pattern. The teacher is given a more important function to ask questions that provide learners the freedom to resolve the problem as they see fit. Encourage the learners to find out things for themselves, and do not tell them more than is really necessary. Let them ask questions about the problem, but as often as possible answer the questions by asking other questions which will put them on a new line of meaningful inquiry. To further encourage learning, the teacher may ask learners to design or construct their own ISPs that have genuine value for them. This can be a daunting task for both teachers and learners as it might not be easy to pay attention to details regarding each learner's conception of an ISP. Nevertheless, achieving this in STEM classroom has to be done in a way that is manageable, and in most cases, has to take place in small-group rather than in large-group situations.

In today's world, we need STEM graduates who are more sophisticated in understanding the uncertainty of knowledge through quasi-reflective thinking when there is uncertainty about a solution to a problem. Therefore, an appropriate educational goal for STEM learners when they address ISPs is to learn to construct and defend the reasonable solutions they propose. An important key to success in teaching ISP solving in STEM fields will be an appropriate choice of problems to solve, and instructional approaches and expectations, so that they match the learners' interests and abilities. As an example, the following task (ISP#1) represents a variety of major disciplines (e.g. physics, mathematics, geography, life science, etc.). The task could be regarded as an immediate class task where learners are invited to address the problem, or it can be assigned to learners as a research project. Whichever we see necessary, sufficient time must be given to learners to address the problem.

ISP#1: Concept of vectors-featuring life in the Sahara Desert

Every day we hear stories of people being stranded in the Sahara Desert. Many survivors have shared their stories of how helpless they felt to find a way as there are often no landmarks or clues to guide them. However, the Sahara Desert is a home to many ants, such as Cataglyphis forties. When one of the ants forages for food, it travels from its home nest along a haphazard search path searching for food. The ant may travel more than 500m along such a complicated path over flat, featureless sand that contains no landmarks. Yet, when the ant decides to return home, it turns and then runs directly home.

How does the ant know the way home with no guiding clues on the desert plain?

Learners are invited to use their integrated knowledge resources of various subjects to address the problem. Physics learners might approach the problem using a variety of vector concepts and analytical tools of epistemological framing, as well as blending ancillary information with the use of math-in-physics. Mathematics learners may use their knowledge of bearings to develop and defend mathematical arguments. Life science learners may use their knowledge of bifurcation and topological change in relation to the behavior of the ant to develop and defend arguments. Geography learners may approach the problem using their knowledge of geomorphology, by tapping into plane Euclidean geometry, spherical geometry, trigonometry, and so on. In all cases, learners must draw upon relevant knowledge, present a reasonable solution, and support it with sound arguments as well as producing grounds to refute an anticipated opposing position.

Teaching 21st Century Competencies and Skills through Argumentation

The twenty-first century learners need an instructional approach that offers learning opportunities through authentic real-world contexts. A growing body of research shows that collaborative learning is a twenty-first century trend that shifts learning from teacher or lecture-centered settings to learner-driven settings. In the latter setting, teachers must ascertain what knowledge resources individual learners have acquired or still need to acquire, so that they can decide whether to move forward with covering the curriculum or reviewing existing ways of knowing in greater depth (Barkley et al., 2014; Facer, 2012). In the manner now being indicated, learner-centered teaching merged with argumentation can offer great opportunities to prepare the twenty-first century learners for life beyond graduation. Kuhn (2010) and others (Belland, Glazewski, & Richardson, 2011; Evagorou & Osborne, 2013; Ogunniyi, 2007a) state that an argument is a form of discourse that needs to be appropriated by learners and explicitly taught through suitable instruction, task structuring and modelling (Simon et al., 2006). Thus, argument refers to the substance of claims, data, warrant, and backing that contributes to the content of the argument, whereas argumentation refers to the process of assembling these components, as espoused by Toulmin (2003). From this perspective, argumentation is the process of making a claim and providing justifications for the claim using evidence (Kuhn & Udell, 2007).

Therefore, situating argumentation as a central element in the design of ISP-based learning and projects has two functions: (1) how arguments are used by learners in STEM fields for the construction of projects or ISPs solution pathway; and (2) the development of criteria used by learners in STEM to evaluate the selection of evidence and the construction of explanations to refute an anticipated opposing position when it arises. What this then means is that STEM should not only involve transmitting a set of known facts to learners, but should also focus on encouraging learners to engage in critical and inventive thinking about STEM concepts, to support their claims using evidence, and to justify their ideas with practicable explanations (Kuhn, 2010; Voss, 2006). This should be seen in relation to providing learners with an ISP-based learning activity which supports equitable opportunities for collaboration, discussion and debate and teacher-learner active engagement in constructing arguments through the process of argumentation (Belland et al., 2011; Simon et al., 2006).

In order for each learner to be able to pursue his or her own course of action during ISP solving, the teacher should see to it that the conduct and organization of the class should at least support three practical forms of argumentation: *analytical*, which is grounded in the theory of logic and proceeds inductively or deductively from a set of premises to a conclusion; *dialectical*, which occurs during discussion or debate; and *rhetorical*, which is employed to persuade an audience (Toulmin, 2003). The teacher should realize that, to conduct argumentation instruction well, proper preparation is essential. The unprepared teacher will not be in a position to ask questions or make comments that will help to bring his/her learners to the point where they will be able to reach reasonable conclusions for themselves. Also, the teacher should have such a good grounding in the subject that he/she can visualize what the course and outcome of the argument is likely to be, even if the discussion takes an unexpected turn, his/her background in the subject would then help to deal with the situation.

Furthermore, some teachers tend to monopolize the discussion, intervene too soon on behalf of a speaker, and supply additional information themselves. It is important that the learner should, in his/her struggle to express himself or herself clearly, be given the opportunity to arrange his/her thoughts and improve his/her powers of expression. What the learner needs at this stage is the encouragement given by the teacher in order to advance to a higher level of thought. They should have the chance to reason, think, argue, critique the problem and the propose solution(s) as they see fit, make and defend their judgements and communicate the outcome in their own words. The teacher should not take over this burden from the learners. Learners going out of their way to talk over their peers, or to prove how clever they are, can spoil the purpose of teaching and learning ISP solving through argumentation. It is important that learners should be willing to listen and to take one another seriously. The example of the teacher is extremely important in this respect. Therefore, the creation of a respectful atmosphere in which learners can enter into a dialogue or conversation about a given problem is essential. The teacher should be friendly and natural at all times, but business-like rather than an authoritarian or a slack. Without these basic requirements, teaching ill-structured problem solving through argumentation instruction can become little more than time-wasting chatter or a nightmare to learners.

An important insight that has developed from the researcher's prior work shows that it is important not only for learners to be able to make sense of data to construct claims, but also to be able to consider alternative claims and to critique the claims and justifications provided by their fellow learners in the context of dialogic interactions (Iwuanyanwu, 2019). As an example, a learner is assigned to solve the ISP#1, titled "concept of vectors-featuring life in the Sahara Desert". The question reads, *'how does the ant know the way home with no guiding clues on the desert plain?'* First, the learner will need some form of model that supports the construction of a problem representation phase. The model may consist of a Claim, which is the basic argument, the Grounds (or Warrant, which relates to the Data and Claim), and the possible Backing for the Claim. For example, the learner makes a Claim that *"the desert ant keeps track of its movements along a* *mental coordinate system"*. This Claim can then be challenged by his or her peers who might ask 'what reasons have you got to go on?' The learner can then appeal to the relevant knowledge resources at his or her disposal, known as Data. In addition, the learner can support his or her line of reasoning using a problem representation phase (vector diagram), which presumably points to the locus of the ant's home nest (Figure 1). At this point, whether the facts provided by the learner (solver) are accepted by the challenger or not, do not necessarily end the argument. This allows the claim of one argument to serve as the data of a second argument, thus permitting argument continuity. Following this, the challenger may ask the learner (solver) about the bearing of data on the claim that he or she has made. For example, by asking the question, 'how do you get there?' This question engenders the construction of a proposition known as the Warrant. By this, the learner (solver) must have recourse to use data to make a conclusion or claim. The learner goes on to say that *"when the desert ant wants to return to its home nest, it effectively sums its displacement along the axes of the mental coordinate system to calculate a vector that points directly home"*.

Again, different degrees of force on the conclusions may be raised by the challenger, *indicating circumstances in which the authority of the warrant is set aside*. The challenger may ask 'Why do you think that?' Thus, the learner (solver) will have to provide an answer that corroborates his or her thought. As backing, the learner (solver) may point out that the proposed mental coordinate system of the ant would permit some form of calculations, by taking variables and instances (shown in Figure 1 below) as constrain conditions to be examined on their own merit. As an example of such calculation, let us consider the ant making five runs of 6cm each on an $(x; y)$ coordinate system, in the direction shown in Figure 1, starting from home.

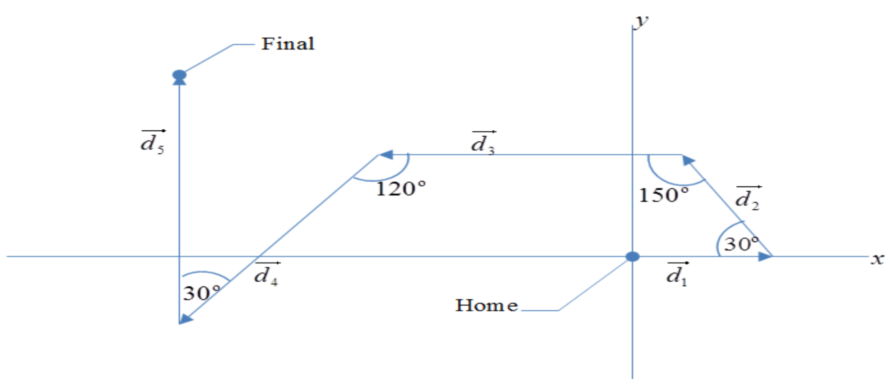

Figure 1. Representation of mental coordinate system of the ant's movement.

The learner (solver) can propose solutions for what he or she thinks the magnitude and angle of the ant's net displacement vector presumably are, and what those are of the homeward vector that extends from the ant's final position back home. Having made this point, the learner acknowledges that different solutions are possible. We consider those that we think are worthy of consideration, rule out some and leave them undetermined until more convincing evidence emerges.

In another related case, a teacher may, for example, design an activity that shows the need for aid relief supplies to be transported to an area where the road leading to the aid recipients is blocked (Figure 2). Some explanation may be helpful for understanding how the task can be approached. The teacher may ask learners to design a simulation vehicle, which is capable of transporting goods, able to navigate down slopes, and, if obstacles are encountered, should be able to launch its cargo successfully to the desired target (Yu et al., 2015). The composition of the task requires various STEM sources such as knowledge of classification, terminology, principles, theories, models, structures, algorithms, and strategies needed to execute the task. Since the nature of the task depicts a teaching and learning approach in which science, technology, engineering, and mathematics (STEM) are purposely integrated, learners will need to develop a utility blending of auxiliary information for STEM problem organization and solution. This may lead to a higher form of awareness, and consequently, to a deeper level of understanding from which ideas may move within a learner's mind when discussing the nature of the task with his or her peers.

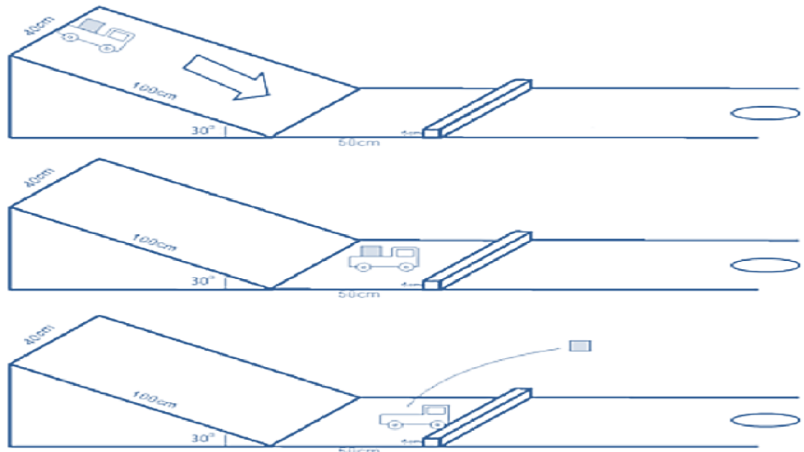

Figure 2. ISP-based learning activity adapted and modified after Yu et al. (2015)

Furthermore, the nature of the task offers opportunities for learners to imagine the problem context and what the key features of the simulation vehicle are, including both visible and invisible features. This involves negotiating both logical and non-logical ideas among learners from a variety of STEM sources. Thus, the utilization of argumentative elements (e.g., claim, evidence, warrant, counterclaim, and rebuttal) and their application within the scope of the problem are essential in fostering reasoning skills among learners to judge the adequacy of the problem solution. Depending on the nature of the arousal context, or the claims to be defended or refuted in the strife to attain a sort of cognitive allostasis, learners with divergent opinions about the task will seek to justify their stances against those of real opponents (Ogunniyi, 2007a). As such, their thinking is directed to analyze and define the problem in a systematic and alternative way, yet leaving a tolerance for ambiguity. This then requires learners to postpone judgment in the evaluation of various options, keep an open mind for alternative solutions, and curiously but skeptically look for other solutions even when one is at hand. It also requires them to carefully analyze STEM resources to help them identify salient features of the problem. In doing so, they make claims and defend their claims or counterclaims with reasonable arguments. At any rate, they make decisions and adopt a plan for solving the problem. The plan to be implemented must be attentive to details. At the beginning of implementation, the learners apply whatever level of understanding they have in STEM domains, and see if they can reach a satisfactory solution. In the event of not being satisfied, the learners are then encouraged to stretch towards a more satisfactory solution by working further in some newish areas (other domains) until they obtain more satisfaction.

To integrate the foregoing into a sensible mental framework, STEM teachers may want to assess the dynamic cognitive states that each learner or group of learners adopt while trying to solve the problem. The key issue that has to be considered is that learners will differ according to the STEM sources from which they cultivate their argument and in the levels to which they develop it. Therefore, to create the needed intellectual space for appraising the interface of STEM ideas as they unfold while the task is being executed, Ogunniyi's (2007a) Contiguity Argumentation Theory (CAT) provides valuable theoretical and analytical support for evaluating what counts as feasible solutions to the task in terms of the logical and non-logical arguments that learners will generate. Essentially, CAT consists of five dynamic cognitive stages (i.e. dominant, suppressed, assimilated, emergent and equipollent) that teachers can use to evaluate learners' ideas while executing intricate tasks. During each of these stages, there is a unique level of analysis, an internal organization and understanding of the cognitive shift that happens in the mind of the learner. Dominant refers to a learner's most prevalent worldview or ideas being mobilized within (or across) STEM fields to solve a problem. Suppressed refers to a learner's thought system in which a unit of STEM ideas is subdued by the more dominant one. Assimilated refers to a unit of STEM ideas that is subsumed by the more dominant one. Emergent refers to the STEM ideas that evolve from a new experience, e.g. the acquisition of a new concept in STEM fields. Equipollent refers to two or more STEM ideas exerting equal cognitive force on a problem solver's solution pathway. This again requires STEM teachers to make the ways in which learners' ideas unfold explicit to learners. In a way that is appropriate to the particular circumstances, learners learn not only what counts as justifiable solutions, but how the execution of the problems, such as those depicted in Figure 2 and ISP#1, fit into evidenced-based argumentation. The strength of such an approach is that learners can look back with objectivity over the entire process, and communicate their new knowledge to others, and additionally, show how the learned knowledge and skills can be applied to other contexts.

Constructing Solutions of Ill-structured Problems

The arguments presented so far have shown that ISP-based learning can create new and unprecedented opportunities for learners to develop the essential skills needed to solve STEM problems that are ever-present in real life where WSP-based learning alone is insufficient. The highlights of Figure 2 and ISP#1 buttress this viewpoint. However, some evidence agrees that there are aspects of the teacher's own problem-solving behavior which they do not include in their teaching (Jonassen, 2011a; Shekoyan & Etkina, 2007; Yu et al., 2015). These include the careful reading and re-reading of the problem statement, its translation into sub-problems and required information, the choice of the strategy to be used, and the systematic checking of their implementation of each of its steps. Therefore, to translate these omissions into pedagogy for teaching ill-structured problems (ISPs), this paper suggests that teachers should:

- place an emphasis on the ways to read and translate the statement of ISP.
- engage learners in an active construction of various representation phases of ISPs.
- use explicit teaching strategies of ISPs to demonstrate how they themselves go about solving an ISP.
- recognize that different ISP solvers may vary considerably in the nature and contents based on their knowledge, beliefs, and attitudes.

- know that an ISP may have multiple solutions, and therefore should be judged in terms of some level of plausibility or acceptability.
- know that solutions learners propose to ISPs are justified by arguments that indicate why the solutions will work, as well as producing grounds to refute an anticipated opposing position.
- emphasize that the solutions of ISPs often are not final, in the sense that they need to be implemented (tested) and evaluated to see if it will really work (Voss, 2006).

As opposed to WSPs, the constraints of ISPs, such as found in everyday life or in many subject matter contexts, typically are not in the problem statement (Voss, 2006). The problem solver (learner) needs to retrieve and examine the constraints (as depicted in Figure 3), when appropriate, during the solving processes.

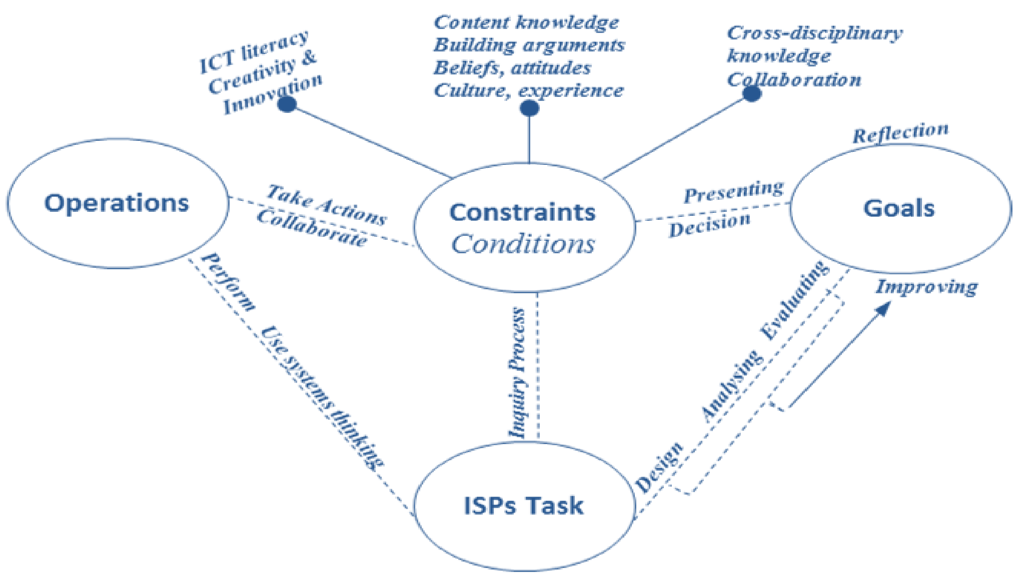

Figure 3. Integrated features of ISPs depicting utilization of many skills.

Figure 3 shows the perspective of an ISP task depicting the activity-processing features that can be advanced by a problem solver in relation to particular task goals. Taking appropriate action to solve an ill-structured problem is realized through operations directed by constraints or conditions which include learners' existing knowledge, experience, intellectual capacity, and the resources and tools available to achieve the desired goals. Available evidence suggests that the acting problem solver (learner) is motivated by unanticipated interruptions to the flow of the solution process. Evidence is shown in Tweney's (1981) study of Michael Faraday's notebooks during the course of Faraday's discovery of electromagnetic induction. The solution process quite substantially followed the course of solving ill-structured problems. On the basis of this assertion, investigating whether a student knows "p" will inevitably include watching him or her do something that closely resembles "p". If knowing and doing are so closely intertwined (Barron & Darling-Hammond, 2008), one should not ignore the real-world setting in which the learner does "p".

As an example, assume the problem is to find if a physics learner can demonstrate evidence that s/he can retrieve and examine the constraints embedded in the fourth equation of the Lorentz transformation $t^{'} = \frac{t - \frac{v}{c^2}x}{\sqrt{I - \frac{v^2}{c^2}}}$ as well as producing grounds to refute an anticipated opposing position. The learner may begin by constructing the representation phase of the equation. However, doing so may not satisfy other indicators of understanding, such as recognizing the interplay between each symbol and any other with which it may appear. One move the learner is likely to make is to ascertain conditions to which each of the variables of the equation applies or does not apply. Essentially, the same tenet holds if the learner must resolve that time difference $\Delta t^{'}$ of the two events with respect to $K^{'}$ in general does not vanish, even when the time difference Δt of the same events with reference to K vanishes. In the main, the pure "space-distance" of the two events with respect to K results in "time-distance" of the same events with respect to $K^{'}$. At this point, the teacher may need to ascertain whether the learner also recognized the most essential property of the equation as a three-dimensional (3D) continuum of Euclidean geometrical space. The difficulty in recognition affects other cognitive factors, such as the strategy a problem solver employs to create a solution as well as the host of arguments generated to support the solution (Belland et al., 2011).

To help learners in STEM fields acquire mastery in this area and become experts in producing knowledge rather than consuming it, we must capitalize on their interests by ensuring the ultimate goal of ill-structured problem-based learning and projects is to stimulate their capacities to create and generate ideas, concepts and knowledge (Jamaludin & Hung, 2017; Jonassen, 2011a). In the same vein, it is imperative to recognize when learners cannot immediately achieve those goals. STEM teachers should set intermediate targets for learners by breaking down learning into meaningful segments, so that interest is sustained (Netwong, 2018; NRC, 2012).

Implications for the 21st century STEM pedagogy

What is next for equipping twenty-first century learners with the skills and competencies to function in the ever-expanding global digital world, known as the fourth industrial revolution? Most likely, pressures may vary from discipline to discipline, but the message is fundamentally the same for science, technology, engineering and mathematics (STEM). Re-skilling and updating competencies will enable learners of all ages to adapt to new STEM expectations in the twenty-first century workplace and life. Ultimately, assessment that focuses on a learner's mastery of STEM's core academic content and the development of deeper learning skills (i.e. critical thinking, problem solving, collaboration, communication and metacognition) should be a high priority (Gijisbers & Schoonhoven, 2012; Jamaludin & Hung, 2017; NRC, 2012; UNESCO & UNICEF, 2013a). To foster this commitment as the paradigm for the future is to expect that learning strategies and pedagogical approaches will undergo drastic changes and create new pathways for learners of all ages. Information and Communications Technology (ICT) should also be used to permeate learning activities and be integrated into learners' real-world experience as a way to foster creativity and innovation. The proposal for using ISP-based learning and projects with linkage to argumentation instruction can be a way to equip learners to tackle twenty-first century challenges and pressures. However, a necessary collocation to this is that formative assessment must be appropriated as a practice to support learners. Thus, the attainment of this will equally require teacher education programmes to shift their orientation to twenty-first century principles of teaching and learning.

Closing Thoughts

As this paper has clearly demonstrated, one clear goal of ISP-based learning for STEM learners is that different individuals can have different but reasonable positions on the same issue. Fundamentally, therefore, whatever we teach them must be taught thoroughly so they can use it confidently and correctly in whatever decisions they later make, whether in their private lives, in societies or in their future professions. This also means that STEM teachers must ascertain the individual learners' process of adapting new knowledge for their own use and incorporating it into their existing knowledge and skills. This, in turn, nurtures critical thinking skills, creativity, originality, and establishes new cognitive habits (Lai, 2011). However, for transfer to occur, learners need to apply new learning and practice new skills in different situations and contexts.

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Perceptions of K-12 Teachers on the Cognitive, Affective, and Conative Functionalities of Gifted Students Engaged in Design Thinking

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ABSTRACT

Gifted students are our nation's natural resource of technological inventors and innovators, but oftentimes do not receive differentiated instruction in technology/engineering design learning environments. This is not negligence or lack of care by the instructor, but a national issue of not sufficiently providing pre- and in-service teachers with formal training opportunities in gifted education. The purpose of this study was to understand the perceptions of K-12 teachers, trained in gifted education pedagogy and the Design Thinking Model (DTM), after their gifted students engaged in design thinking activities. Fifteen K-12 educators of different content areas reflected in focus groups upon how their gifted students performed. Teachers noted cognitive, affective, and conative phenomena, such as development of 21st Century capabilities, externalizations of psychosocial behaviors (e.g., perfectionism, avoidance of failure, gifted underachievement), and strong motivations to solve problems for end-users. The researchers suggest that with the reality of educators unable to receive formal training in gifted education, developing an awareness of intrapersonal functionalities of gifted students engaged in design thinking can be a significant step toward providing supportive learning environments.

Keywords: Design thinking; Design Thinking Model; gifted education; Technology and Engineering Education

Introduction

Today's educators are tasked with preparing a diverse, heterogeneous group of students for complex and undetermined jobs. Two key components of this charge include (a) understanding unique students' needs and characteristics, and (b) implementing pedagogical practices that develop 21st Century capabilities such as collaboration, communication, creative and critical thinking (NCTE, 2013; Partnership for 21st Century Skills (P21), 2011; Snape, 2017; Walser, 2018). First, regarding student needs, most classrooms are grouped by chronological age, rather than educational readiness, resulting in students with abilities spanning six to ten grade levels (Diezman et al. 2001; Firmender et al., 2012; Peters et al. 2017). The majority of teachers' time is spent addressing students who are struggling, while overlooking average and advanced students (Farkas & Duffett, 2008). This may be occurring due to extreme pressure to meet state and national standards (Moon et al., 2007), but it may also be due to a lack of teacher preparation in differentiation, especially for gifted and talented students. Within the United States, on average, pre-service teachers receive less than two hours of total instruction on meeting gifted students' needs (NAGC, 2015-a), and often, professional development opportunities are ineffective at changing classroom practices (McCoach & Siegle, 2007; Peters & Jolly, 2018).

The second challenge is to integrate pedagogy that facilitates 21st Century capabilities into the curriculum; however, given the current educational climate, this too can be difficult. Most state and national assessments emphasize knowledge acquisition or lower level process skills in language arts and math. The outcome is reduced classroom time spent on other subjects and less time devoted to deeper level process strategies (Au, 2007; Dee & Jacob, 2010). One strategy to address both of these challenges is to integrate design thinking opportunities into all classrooms.

Literature Review and Theory

Design Thinking

Across myriad industries, design thinking has many definitions and meanings (Buchanan, 1992). Within this article, design thinking is conceptualized as a paradigm for innovation and a process for problem solving (Dorst, 2011). Dym and colleagues (2005) refer to design thinking as a "systemic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specific set of constraints" (pp. 104). While these definitions explain the purpose, recent stage-based models provide explicit guidance on how to facilitate the process. The Design Thinking Model (DTM) provides a linear, yet recursive five stage process: empathy, define, ideate, prototype, and test (Plattner, 2010; Cook & Bush, 2017). Table 1 summarizes the five steps.

Technology educators have been promoting design thinking for years, including studies examining how educators implementing design thinking to teach mastery of STEM content, art, and humanities (Bequette & Bequette, 2013) and cognitive processing skills (Lammi & Becker, 2013; Shively et al., 2018). Previous studies of design thinking within curriculum and instruction suggest this pedagogical approach positively impacts the learning experiences of traditionally underrepresented populations in STEM disciplines (Kramsky, 2017; Santovec, 2012, Tyler & Johnson, 2017). In general, design thinking tasks can be approached from different readiness levels and intellectual abilities, making them a natural method of differentiation in heterogeneously grouped classrooms (Gentry et al., 2008). Further, these tasks are interdisciplinary, require the integration of content knowledge, and promote deeper cognitive processing.

Table 1
Summary of Design Thinking Model (DTM)

Stage	Description
Empathy	Connect with the end-user and learn as much as possible about this person's wants and needs.
Define	Develop a specific problem statement inspired by the empathy engendered in the prior stage. The purpose of this stage is to clearly identify a logical goal designed to solve the end user's want/need.
Ideate	Research, generate, modify, and co-construct new versions of ideas to fulfill the goal
Prototype	Select an idea(s) to create a prototype and justify the decision. The purpose of this stage is to create a model of the idea, moving the abstract to a tangible or representative form.
Test	Experiment with the prototypes to evaluate functionality and ability to address the problem of the end-user. Consider the information gathered and developed within previous stages to revise and redesign ideas, prototypes, and eventually re-test them within the cyclical structure of DTM.

Gifted Students and Design Thinking

While design thinking addresses these current needs (i.e., supporting a heterogeneous student population in the development of 21st Century capabilities), little research considers how gifted students actually engage with design thinking and the outcomes of DTM implementation. A literature search using the terms "gifted" and "design thinking" in several databases (i.e., Academic Search Premier, PsychINFO, PsychARTICLES, and ERIC), yielded seven journal articles. Many gifted students may have unique reactions, experiences, and stressors as their talents intertwine with their still-developing physical and emotional maturity (Field et. al., 1998), and many educators may not be prepared to recognize these unique needs and characteristics (NAGC, 2015-b). Gifted students' unique characteristics could be conceptualized as: cognitive (i.e. intellectual abilities and higher order thought processes), affective (i.e. emotions and emotional development), and conative (i.e. motivation and motivation development). With these additional complexities of giftedness, gifted students may be uniquely impacted when engaging with design-based learning experiences.

The federal definition of giftedness is:

> Students, children, or youth who give evidence of high achievement capability in areas such as intellectual, creative, artistic, or leadership capacity, or in specific fields, and who need services and activities not ordinarily provided by the school in order to fully develop those capabilities (NCLB, 2002).

However, states and districts are not required to use this definition. The students of this study were identified based on Indiana's identification measures as they performed, or showed potential for performing, at an "outstanding level of accomplishment in at least one domain when compared to other students of the same age, experience, or environment; and is characterized by exceptional gifts, talents, motivation, or interests" (Indiana Department of Education [IDOE], 2013, para 3). The local school district of the students further specifies the domains, often math and language arts.

In 2013-2014, there were approximately 3.3 million students in the United States enrolled in gifted and talented programs (Office of Civil Rights, 2014). Gifted program coordinators, teachers, educational leadership, and families often work collaboratively to provide critical services to meet the diverse needs (e.g., academic, cognitive, social, emotional) of the gifted student. Advocacy measures call for the continued support of gifted students to develop competencies for success in the 21st century; however, lack of financial resources and unfamiliarity with gifted student characteristics may lead to students not receiving the services needed (NAGC-a, 2015).

Technology and engineering education, career and technology education, and displine predecessors are ideally positioned for intersections of natural differentiation, relevancy, and creativity to benefit gifted students (Brenneman, Justice, & Curtis, 1980; Colson, Milburn, & Borman, 1983; Dailey, 2017; Dailey, Cotabish, & Jackson, 2018; Gentry, Hu, Peters, & Rizza, 2008; Mentzer, Reed, Alnouri, & Barbarji, 2018). According to Mann et al. (2011):

> For students who have been identified as gifted but spend the majority of their day in regular education classrooms, engineering design activities present opportunities for varying levels of sophistication, breath, and depth of understanding, thus providing them with appropriately challenging tasks" (p. 651).

Unfortunately, technical programs remain an afterthought for gifted student programming or they are even perceived as inappropriate by educational colleagues outside of the technology education field (Greene, 2006; Gentry et al., 2008). Compounding this issue, many technology and engineering educators are unfamiliar with the complex spectrum of gifted characteristics and aptitudes. The most talented students may be overlooked and do not receive sufficient attention in classrooms (Gentry et al., 2008).

Study Objectives

Therefore, to prepare teachers to support students in solving complex problems, our research team implemented DTM professional development workshops with K-12 teachers to design and actualize classroom DTM learning experiences. The purpose of this study was to understand the impressions of K-12 teachers teaching who implemented the DTM with gifted students within their inclusive classrooms. Within focus groups, researchers, who were not involved in the professional development sessions, discussed with the teachers how gifted students responded to the DTM learning experiences. Gifted students were placed in inclusive, hetergeneous classrooms, grouped with peers who were not identified as gifted. The transferability of this study to other classroom environments is notable, as it is likely that education practitioners of design thinking across the nation also have gifted students embedded within the general population classrooms. Thus, this study presents teachers' observations and perceptions of gifted students' cognitive, affective, and conative characteristics when engaged in design thinking.

Method

This investigation used a qualitative approach as a means to promote deeper understanding of human experiences (Bogdan & Biklin, 1992). Teacher participants received voluntary, paid, professional development training on DTM for two weeks during the Summer 2017 and continued professional development/coaching once a month throughout the 2017-2018 academic school year. Teachers completed surveys, submitted DTM unit artifacts online, and participated in focus groups sessions to share their experiences using the DTM in their classrooms. This study examines the focus group data pertaining to gifted students. Focus groups for this study were used for the following reasons: a) within this specific school, teachers often act as a collective group and share students, b) teachers' attitudes and perceptions already influence each other in the natural school environment, and c) the existing comfort and relationships allow for a more candid conversation than would happen with individual interviews. The focus group conversations were audio recorded, transcribed, and analyzed for overarching themes.

Sample

The teacher participants of the focus groups (n = 15) taught K-12 across different content areas- including arts and humanities. Thirteen of the participants were female and over 50% of all participants had 15 or more years teaching experience. The choice-based school accepts a higher than average number of gifted students (i.e., 20% or more of each class is earmarked for students identified as gifted through state testing procedures). The teacher participants have received, or are in the process of receiving, gifted and talented teaching licenses in a nationally accredited gifted licensure program.

Data Collection

Focus group interviews were conducted with teacher participants in small groups ranging in size from 2-5 teachers. Focus groups, rather than individual interviews, are particularly beneficial when the experiences and understandings of participants are socially constructed (Merriam, 2009). In this case, homogenous groups comprised of teachers who work with similar grade level students, and often collaborate on unit design and planning, were chosen which can help encourage open discourse (Sagoe, 2012). This was particularly beneficial because their shared experiences allowed them to hear each other's thoughts, spark conversations, allow for thoughtful reflection, and ultimately add to the richness of the data (Merriam, 2009; Patton, 2002). The focus groups were facilitated by two interviewers with no existing connections to the school or the DTM professional development, further encouraging open discourse. Each focus group lasted approximately 45 minutes, conducted on-site, in a closed classroom allowing for open discussion. All participants were informed of the focus group's purpose and were assured of confidentiality.

Semi-structured interview protocols are an effective way to allow researchers to explore what is important to participants in a conversational tone, while still covering similar topics across groups (Merriam, 2009). A semi-structured interview protocol was developed for use with the focus groups prior to data collection and utilized similarly with each focus group to capture open-ended responses (See Appendix A). Questions were developed as open-ended questions, intended to encourage discussion among participants without prompting or leading to certain responses. Teachers were asked to reflect about their overall experiences with DTM and their students' experiences, but they were not led to discuss cognitive, affective, and conative characteristics, as those characteristics emerged after data collection. All focus groups were audio recorded and transcribed for further analysis.

Data Analysis

To support the canons of validity, this study's data analysis replicates Anafara, Brown, and Mangione's (2002) approach for transparency in the coding process (See Table 2). It should be read from the bottom up, as the raw data serves as the foundation anchoring the process, leading to the development of themes. After transcribing the raw data, the researchers individually read and reread the data to familiarize with the focus group texts. With the first iteration, the responses underwent a surface content analysis of initial codes. In the second iteration, pattern variables were identified. The third iteration of analysis addressed applications to the data set. After coding all of the data separately, condensing the codes, and a final read of each transcript, the researches met together to reach group consensus of coding results, and then collapsed the codes into themes to convey rich, thick description. Though an inherently inductive study, the primary investigator recognized the pattern variables of the second iteration unintentionally represented the operational definitions of interpersonal, gifted functionalities (Moon, 2013). Therefore, the inductive codes were organized and categorized under this existing theory.

Table 2
Code Mapping of Data Pertaining to Teacher Perceptions of Gifted Youth*

<table>
<tr><th>Focus Group A</th><th>Focus Group B</th><th>Focus Group C</th><th>Focus Group D</th></tr>
<tr><td colspan="4">Third iteration: Themes</td></tr>
<tr><td colspan="4">Cognitive Development: Design thinking provides an opportunity for gifted students to develop 21st Century capabilities.
Affective Development: With an open-endedness of design thinking, gifted students needed to develop more adaptive methods for collaborating and addressing their perfectionism and avoidance of failure/risks.
Conative Development: Design thinking leads to motivation, engagement, and self-direction.</td></tr>
<tr><td colspan="4">Second iteration examples: Pattern variables</td></tr>
<tr><td>• Students collaborated with peers and showed creativity and critical thinking
• Emotional challenges: perfectionism, avoidance of failure, and gifted underachievement</td><td>• Students initially experienced difficulty in design thinking, but found the process to be rewarding when solutions were successful
• Inspired to invent and innovate</td><td>• Students enjoyed the real-world relevance and helping others.
• Failure was negatively perceived for many gifted youth, and they did not want to participate</td><td>• Students had to think creatively and critically to solve real world problems
• Motivated to be correct right away instead of going through multiple iterations</td></tr>
<tr><td colspan="4">First iteration examples: Initial codes**/surface content analysis</td></tr>
<tr><td>88. Collaboration generated in ideas
91.A. Excited by prototype success
94.B. Problem solving and communicating
94.C. Compared to non-gifted, experienced greater challenge in design
100.A. Taking control of group</td><td>77. Real world relevance
87.A. Preference for design thinking activities.
87.B. Strong engagement by students with excitement
102.A. Difficulty adapting ideas</td><td>34. Learn by doing
147.A. Empathy, enjoy coming up with solutions to help others
147. B. Purpose to design thinking
232.A. Students pumped
232. B. Failing with grace</td><td>201.A. Experienced greater difficulty than non-gifted kids to solve ill-defined problems
201.B. Driven to be 100% correct
201.C. Challenged, later developed design thinking capabilities</td></tr>
<tr><td>Raw data</td><td>Raw data</td><td>Raw data</td><td>Raw data</td></tr>
</table>

**The numbers correspond to the initial codes agreed upon by the researchers. With this numeric system, multiple researchers could locate codes in need of consensus throughout subsequent iterations.

Quality Criteria

The current qualitative study exacted deliberate methods to establish and ensure quality criteria were met including credibility, transferability, dependability, and confirmability (Lincoln & Guba, 1985). To promote transferability, the findings and sampling strategy were transparently presented in this article to foster replication of the study or application of the study in various contexts. The findings reflect an iterative process of categorizing and analyzing the qualitative data among multiple research members. The themes were reviewed repeatedly and by different members of the research team. This flexibility of analysis process increased the dependability of the study and ensures the quality of findings with relation to the context of the study. Through similar methods, the study ensured confirmability by utilizing peer reviews, researching literature in the field of gifted education and technology and engineering education, and tracking changes throughout the research and analysis processes.

Results

The findings describe K-12 teachers' perceptions of how gifted students engaged in design thinking. Students were expected to use the DTM (Empathy, Define, Ideate, Prototype, Test) to solve a problem for an end-user. The subsequent outcomes were discussed in the focus groups.

Cognitive Development: Design Thinking Provides an Opportunity for Gifted Students to Develop 21st Century Capabilities

Cognition refers to "mental processes or forms of informational processing" and includes skills such as attention, memory, learning decision-making, reasoning, and problem solving (Solomon, 2013). Gifted students were cognitively challenged throughout the process in multiple ways. Design thinking in the classroom forced students to develop flexibility within their thinking; however, this was not easy. One teacher described the struggles associated with specific stages:

> ...if you tell them, 'no, you need more', they'll just write down something...they're not really thinking, they have made their decision, then they're just trying to appease you. The other thing, when they're thinking about evaluation testing, they're going to say it's okay, because they don't want to go back and fix it.

Another teacher observed the struggle with cognitive rigidity, "My higher group, they're the ones that did the worst compared to the other kids. Because they [gifted students] couldn't adapt their ideas, 'no this idea has to work, it will work,' ...they couldn't move past it."

Similarly, an additional teacher shared:

> For some of our high ability students, [DTM has] been more of a challenge because they're used to succeeding. [When they] have to really problem solve and translate what they created on paper into a creative 3D project, that was very difficult. Our other students, they just went at it. They just did it.

Gifted students may have faced additional challenges because their original ideas were so complex and intricate that they were challenging to bring to life. One teacher commented, "Sometimes I think for our high ability students … it was how elaborate their thought process was, and so to create that was almost impossible. So, I think that that was part of the problem with our [gifted students].” Therefore, these students were cognitively challenged to translate their original ideas into functioning prototypes.

Affective Development: With an Open-endedness of Design Thinking, Gifted Students needed to Develop more Adaptive Methods for Collaborating and Addressing their Perfectionism and Avoidance of Failure/Risks

Affective growth is part of human development, which includes a combination of emotional development, emotional regulation, and recognition of socially appropriate responses toward the emotional functioning of others (Yirmiya & Seidman, 2013). Teacher participants emphasized how DTM experiences impacted students’ affective development, including students’ social skills (i.e., collaboration) and emotional regulation (i.e., perfectionism and avoidance of failure).

Collaboration

Within the DTM tasks, students were often placed in groups to tackle certain tasks. In general, teacher observations indicated differences in how students at varying levels reacted to collaborative learning experiences. Teachers discussed how most students worked cohesively in DTM groups rather than displaying competitive behaviors:

> They pick up on, “...my friend needs me to help with this,” so there isn’t an, “I’m smarter than you, I’m going to do this,” it’s just...they start looking at skills and talents and they look at who draws people better than someone else, who is [best able] to write this sentence…

The conversations were problem/solution focused and students supported each other. As one teacher described, “I really loved when they were working, and a friend would say, ‘Did you think about using this,’ or, ‘Have you thought about this?’ that creates [ideas] and stimulates the kids.” Several teachers reflected on the way in which students collaborated and celebrated small successes. One shared, “They cheered when the houses stood…they [the students] even cheered when their friends or their dwellings stood and withstood [the external forces during the testing phase].”

Yet, as teachers shared their positive observations of student reactions, they also noted negative group dynamics. For example, one teacher described:

> One of our identified high ability students was trying to take control of the whole situation and not listen to anyone else and not accept anyone else’s suggestions. Constantly saying ‘I already know this this is what we need to do.’ At the end, he panicked and…for the life of him, he couldn’t understand as he looked around at the other groups and they were successful. ‘Why were they successful and his group not, especially when he was in charge?’

Conversely, other gifted students struggled to find their place within the group: “[this student] could not find his niche in this group, and he struggled, he said, ‘they’re not letting me do this, or they’re not giving me a job to do.”

Perfectionism and Avoidance of Failure

Teacher impressions were largely positive because even when DTM tasks were challenging, these tasks provided students with opportunities to develop their social and emotional skills. Specific examples of perfectionism, and avoidance of failure were also discussed. Often those experiences led to breakthroughs, but the struggle was significant. One teacher elaborated, "At first they struggled, because it had to be right, and it had to be perfect, and they thought there was only one right answer. And the more we've done it, they're like, 'okay, let's go!'"

The gifted students needed to learn to handle failure and setback, which the teachers identified as supporting students' emotional regulation capabilities. This observation was echoed by multiple teachers across grade levels. One teacher shared, "Our more general ability students seem to take it in stride." Another teacher added, "Failure is more of a debilitating, hard to come back from thing for [the gifted] kids." With more exposure, several teachers observed positive growth. A teacher shared, "[The students were] pumped, once they realized that failure was okay." As one teacher stated:

> My high ability kids were my hardest to break from the one right answer mentality. They were really, really, really driven on 100 percent correct, all the time, being told that they were correct. So, getting them to break and try different things for the same purpose was a little challenging. Now, once they get out of that habit, they were like, off the charts…but at the beginning, it was really tough.

The elicitation of affective responses was perceived by the teachers when activities were anchored in the Design Thinking Model.

Conative Development: Design thinking leads to Motivation, Engagement, and Self-direction

Conation refers to motivation and motivation-related processes such as "goal setting, persistence, and student interests" (Moon, 2013). There are many reasons why DTM tasks promotes motivation, including engagement, differenitation, and interest integration. First, teachers shared how students were actively engaged, excited, and driven to design solutions to improve the life of an end-user. For example, students were tasked with designing a dwelling for the gingerbread man (end-user), and the teacher reflected, "One of our students, when we were building our prototypes and making our models, actually said this was the best day of school ever!" Purposeful design thinking motivated the students, as a teacher explained:

> I have some who don't want to do anything else during the day, but as soon as we do a design thinking project, they are up, they are excited, and you actually see a smile on their face. I have enjoyed that part of it, when I can give it.

Overall, teachers commented about observed motivation toward design thinking in their students. One teacher concluded, "They get to design their projects, and then, just trying to build them, it's a lot of fun!"

Beyond simply enjoying the hands-on nature of design projects, students experienced increased motivation, as they have the opportunity to approach the task at their own levels. In DTM, teachers observed that gifted students are challenged daily while pursuing interests and developing relevant skills. A teacher shared:

> ...it was interesting how everybody got something really important out of it and everybody understood the end game and the goal. The neat thing with this is you don't have to differentiate because they differentiate on their own and they come where they are, and they leave in a variety of different places. Each of them gets their own experience.

Using the DTM, teachers gave students an opportunity to use their talents and explore their interests. One teacher stated:

> The thing that I probably value the most about this was that it allowed each student to shine in their own way...differentiation was an intentional part of them not me. That’s how the differentiation occurred, it wasn’t me specifically saying, ‘Oh, you’re high ability so you’re going to do this,’ or ‘Man you need some help here, I’m going to…’ it was allowing them to work at their own level at their own creative speed...it allowed them to do that, and that’s how I feel that young children learn best.

Another teacher shared more about the differentiation of DTM, “...it’s natural, it is individual, it is not prescribed by the teacher or by the curriculum…it is a wholly natural process.”

Another potential reason for increased motivation was the authentic, transferable nature of the challenges. A teacher described how she used a real-world issue to develop a DTM unit, “…the hurricane project was really relevant to our class because we had just been talking about the Texas hurricane and the Florida hurricane, so they were interested. They’d been hearing about it on the news.” Other teachers reported their observations of learning that transferred to other contexts of students’ days. Referring to the school’s recent science fair, a teacher described one student’s reaction:

> She said, ‘I did this, so to help people know which type of drinking water to buy, which one is healthiest for you, and saves you the most money. You know what I mean?’ She had, right out front, a reason why she had tested all these different bottles of water. I was like, ‘alright, you have a purpose.’ There is application to it.

Teachers were purposeful in their DTM lessons to address local, regional, national, and global problems and perceived that gifted students had positive conative responses with design challenges.

Discussion

The purpose of this paper was to share the reflections of K-12 teachers of their gifted students’ experiences with the DTM within inclusive classrooms. We reported the externalizations of student design thinking observed by participant teachers. The gifted characteristics revealed in this study may be indicative of many gifted students, while still not describing all gifted students. However, similar phenomena may surface in scenarios within other classrooms that implement design thinking or related design-based pedagogy. The themes provided in this study may inform technology and engineering educators in ways gifted students engage in design thinking.

Cognitive, affective, and conative processes are three intrapersonal human functions that were addressed in the data and align with Moon’s (2009) categories of intrapersonal human functioning. Cognitive functioning was addressed by teachers through students’ academic pursuits of design. Affective functionalities were addressed by teachers describing the emotional responses of students to the design challenge and to each other. Conative functionalities were addressed by teachers through descriptions of how the natural differentiation of design thinking created opportunities for student interests to be integrated.

Cognitive Development: Design thinking provides an Opportunity for Gifted Students to Develop 21st Century Capabilities

As research within the field of gifted education has evolved, so have researchers' conceptions of the importance of gifted students' talent development in a technologically driven society (McMath, 2016; Olszewski-Kubilius, Subotnik, & Worrell, 2016). With implementation of DTM, teachers perceived student performance in many ways fulfilled the call for growth of 21st Century capabilities (NCTE, 2013; P21, 2011; Snape, 2017; Strimel, 2012; Walser, 2018). The Pre-K-Grade 12 Gifted Education Programming Standards by the National Association for Gifted Children (NAGC) places great emphasis on gifted curriculum and instruction that provides critical and creative thinking opportunities to students (NAGC, 2010). The teachers perceived these cognitive processes were developed as students struggled with cognitive rigidity. Adaptability was initially a struggle among the gifted students. Teachers noted students were reluctant to fail and hesitated to return to earlier stages of the DTM, however; as experiences progressed, teachers commented that students appeared to grow in this area. Students had to practice the iterative process and seeing solutions from a variety of angles. Their end products were evaluated across multiple components of critical thinking and creativity (for rubrics of novice/developing/expert components see Shively et al., 2018). Students were initially hesitant to provide answers for ill-defined problems, but with more exposure to DTM lessons, they became more fluid with exhibiting the characteristics of good thinkers like graceful acceptance to the ideas of others and pursuing different solutions if the first solution did not work

Affective Development: With an Open-endedness of Design Thinking, Gifted Students Needed to Develop More Adaptive Methods for Collaborating and Addressing their Perfectionism and Avoidance of Failure/Risks

In the focus groups, teachers spent a significant amount of time addressing the interpersonal processes of students. DTM is grounded in human processes such as intuition, pattern recognition, self-expression, emotional meaning, and functional meaning which makes it inherently tied with social/emotional skills sets (Brown & Wyatt, 2010). When students were tasked to flex their social and emotional skills with design thinking activities, the teachers observed social and emotional phenomena well-recognized within the gifted education community.

Collaboration

Teachers shared how students developed communication capabilities throughout the five stages of DTM through oral, written, and artistic forms. The DTM requires students to select a single idea from the multiple ideas generated by the group, and further pushes students to expand, adjust, and elaborate on the solution as they progress. Gifted students needed to learn how to interact with one another and build upon each other's contributions. Some students reportedly began the DTM units viewing themselves as the leaders, but then realized, through vicarious learning, that successful groups had used a team approach. Within groups of varying ability levels, students began collaboratively brainstorming and providing feedback to each other on the originality and usefulness of the solutions, but this needed to be supported. Students were learning to delegate responsibilities and identified unique strengths within their groups during the process.

Perfectionism and avoidance of failure

A prevalently researched roadblock to wellbeing and academic achievement among students in the gifted population is perfectionism (Miller & Speirs-Neumeister, 2017). Students with perfectionism may experience burnout, eating disorders depression, loss of balance with school, family, and friends (Webb, 2016; Greenspon, 2018). Teachers shared that the gifted students ruminated heavily during the ideate, prototype, and testing stages compared to their peers. Some students had to take control of the group's problem-solving efforts to guarantee an absolute solution. However, the phases of DTM necessitates prosocial behaviors when the design challenge is a group activity. The inability to fully control the design challenge caused some students significant anxiety and challenged their emotional regulation. See Adelson & Wilson (2009) or Pyryt (2004) for strategies to support students with unhealthy perfectionism.

Teachers shared that high ability students found failure as an unexpected reality and had difficulty accepting initial design failures as a state separate from their self-worth. Some students initially resisted making revisions when introduced to DTM, but with practice in a supportive learning community, they revised more positively. Once acclimated to the DTM process, teachers found student mindsets shift regarding revisions. Understanding that failure can elicit significant negative affective and physiological stress reactions compared to their non-gifted peers (Roberts & Lovett, 1994), teachers can facilitate the shift to embrace revisions and view failures positively. See Dweck (2015) for a list of strategies to support students with failure avoidance behaviors.

While many gifted students worked extremely hard to avoid failure, other gifted students refused to even try (an alternative approach to avoid failure). Though the teachers did not specifically use the word "gifted underachievement" in their discourse, this phenomenon was alluded to when describing students who wanted to give up instead of attacking the design thinking activity. Gifted underachievers display gaps between measured levels of achievement and measured ability levels apart from any diagnosed learning disabilities (Reis & McCoach, 2000). The complexities of giftedness often lead to social asynchronization with peers and can be noted within collaborative frameworks like DTM. Technology and engineering teachers should also be aware of gifted underachievement as strategies are available in the literature to combat its devastating effects on the academic aptitude of the student. See Siegle (2013) for an inclusive list of strategies to support students who are gifted underachievers.

The Conation: Design Thinking leads to Motivation, Engagement, and Self-direction

Curriculum for gifted students should address their specific needs and provide support in developing their gifts (Marland Report, 1972; Silverman, 1993). Teachers shared the self-directed ways that students differentiated their own learning and chose the pace of stage accomplishment within the DTM framework. Allowing gifted students to use their strengths and work on their weaknesses promoted greater motivation. Specifically, DTM learning experiences provided opportunities for gifted students to grow in their areas of strength by requiring them to use their extensive knowledge base, conceptual reasoning abilities, problem-solving skills, metacognitive strategies, and "expert-like dispositions" (i.e., recognition that a complex problem may have multiple solutions; Gallagher, 2005, p. 287). Further, these learning experiences provide more authentic opportunities for problem solving, which is known as a hallmark of quality gifted curriculum (e.g., Tomlinson et al., 2009).

Conclusion

Among the various complexities surrounding the development of gifted children, they may exhibit unique cognitive, affective, and conative characteristics which require targeted strategies for support. Technology and engineering educators are well-positioned to design and cultivate exceptional learning environments for gifted students. The depth of cognitive and technical skills that can be explored naturally intersects with gifted students' motivations to invent or innovate solutions. Teacher participants perceived gifted students develop their 21st Century capabilities and attitudes in very positive ways; however, it is important to note, there were incidences of productive cognitive and affective struggles as well. Perfectionism, avoidance of failure, and gifted underachievement in particular were observed by teachers as students engaged in design thinking activities. When educators are more aware of gifted students' characteristics and specific resources to support differentiation, they are positioned to make a significant contribution toward designing and creating a positive learning environment for gifted students.

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Appendix

Appendix A.
Focus Group Protocol

1). **Experiences with PD**
   a. How do you think the PD is going?
   b. Thinking back on other professional development training you've experienced what, if any, differences did you notice about the delivery of this professional development?

2). **PD Outcomes for Teachers**
   a. Now, can you share some examples of some ways that you are implementing the learnings from the PD? What are the benefits? Challenges?

3). **PD Outcomes for Students**
   a. How would you describe the reaction your students have had to using The Design Thinking Model?
   b. Tell me about how you prepared for the various levels of learners that make up your classrooms or if you felt the need to do this at all.
   c. Can you tell me about any attempts you've made at assessing student learning as a result of the use of DTM?

4). **Final Reflections**
   a. What else would you like to share about your experiences that we haven't discussed?

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