Advanced Manufacturing Research Experiences for High School Teachers: Effects on Perception and Understanding of Manufacturing

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Abstract

There is significant and growing interest in manufacturing; this is particularly true with respect to advanced manufacturing. Advanced manufacturing typically refers to the use of new technologies to make products that have high value or significant value added through the production process. One of the main impediments advanced manufacturing companies cite is the lack of a skilled workforce. This is the result of both a lack of technical skills, but also due to outdated and incorrect perceptions about manufacturing. Manufacturing is incorrectly perceived as low-skilled, dirty, and low paying. The reality is that a significant portion of manufacturing jobs require advanced technological knowledge and are done in state of the art facilities.

One of the more effective ways to increase knowledge about science, technology, engineering, and math (STEM) careers is to increase the knowledge of teachers. As part of a National Science Foundation Advanced Technological Education project, a group of high school teachers was offered the opportunity to work in advanced manufacturing labs with engineering faculty. These projects included additive manufacturing (AM) of ceramics, surface characterization of AM metal parts, and surface alteration. The teachers were tasked with developing lesson plans which incorporated the advanced manufacturing concepts that they had learned.

As part of the assessment of the program, teachers were given pre- and post- research experience surveys regarding their perceptions of manufacturing and their views of STEM topics in general; the later data were collected using the validated T-STEM instrument. External evaluation also provided feedback on the usefulness of various program activities. Overall participants found their laboratory research and research facility tours extremely useful. They felt that the program enhanced their excitement about STEM and their laboratory skills. Participants also showed significant increases in their post program technology teaching efficacy, student technology use, and STEM career awareness. In addition to empirical results, project descriptions and program details are also be presented.

Introduction

A recent survey by the U.S. department of commerce concluded that while other occupations have a growth rate of 9.8 percent, STEM relevant occupations are growing at 17 percent, almost double the rate [1]. A recent statistic indicates that within the next five years, American companies will need to add 1.6 million STEM-skilled employees to their workforce. Furthermore, according to labor market data, the knowledge and abilities of STEM have grown in demand beyond STEM-specific jobs into all types of occupations [2, 3]. The National Science Foundation asserts that innovations associated with science and technology have increased in their importance over the years and in order to succeed and prosper in 21st century's global economy, students must possess knowledge and skills relevant to STEM. Past studies indicate that the elementary years of education are the best places to lay the foundational knowledge of STEM and therefore it is imperative that students must be given sufficient exposure to STEM subjects starting right from Kindergarten level through 12th grade (referred to K-12 education). But, although multiple studies in the past have assessed that STEM integrated K-12 education is a major driver of United States' continued scientific leadership and economic prosperity, there are many reasons still to be concerned about the state of STEM learning in US [4]. According to a recent statistic published by the National Assessment of Educational Progress in 2013, only 36 percent of 8th graders are proficient or above in mathematics [5]. Employers in a multitude of industrial domains, including STEM fields agree that the job applicants do not possess the necessary mathematics and computer skills to succeed [6]. While investigating the major factors that drive students towards academic success in school levels, the knowledge and beliefs of the school teachers has been found to be extremely important [7]. So the teachers must possess the necessary knowledge, skills and beliefs for providing STEM instructions to the students [8]. However past studies conducted in this particular area have indicated that many teachers lack the necessary knowledge and efficacy beliefs, thereby rendering them inadequate for providing high level STEM education to their students. The objective of this paper is to investigate the effects of a summer residential program geared towards providing high school teachers with insights into the latest in manufacturing research. The goal was to improve their beliefs and attitudes regarding STEM education so that they would feel more capable to impart similar technical information to their students.

The next section of this paper (Literature Review) provides an overview of several papers published in the area of teaching self-efficacy, its relationship with STEM education, and the instruments that have been used for its measurement. The Research Design section describes in detail the methodology and instruments used for the purpose of this study. The Data Analysis section provides a description of the data used for this study and the results of the analysis conducted on it. Finally the Conclusion section summarizes the entire work that has been conducted in this paper and provides a discussion of the limitations present in this study and the scope of future improvement.

Literature Review

Teacher self-efficacy

Self-efficacy is defined as “beliefs in one’s capabilities to organize and execute the courses of actions required to produce given attainments” [9]. Self-efficacy beliefs act as a key factor behind a persons’ thinking, feeling and behavior, and provides confidence in his or her ability to succeed in a specific situation [10]. Individuals who possess a lower sense of self-efficacy tend to perceive themselves as incompetent, do not partake in challenging tasks, and surrender when faced with adverse situations [11]. A subset of the general construct of self-efficacy, teacher’s self-efficacy is defined as the teachers’ confidence in their ability to promote student learning and success [9]. According to Nadelson *et al.* [8], teacher self-efficacy has proven itself to be an important determinant of student learning and it is extremely important for successful teaching [12]. As stated by Anita Woodfolk in an interview [13], “Teachers who set high goals, who persist, who try another strategy when one approach is found wanting—in other words, teachers who have a high sense of efficacy and act on it—are more likely to have students who learn”. Teachers with a strong sense of teaching efficacy were found to excel in areas of planning and organization and more open-minded towards using radical techniques to cater to student needs [14, 15]. This particular aspect of self-efficacy was first identified in 1976 through a study by RAND Corporation [16] as one of the few teacher-specific characteristics that can be related to student achievement. Teacher efficacy has been associated with several positive variables surrounding both instructor behavior and ratings as well as student outcomes [17]. The efficacy beliefs of a teacher can significantly alter their perceptions and judgement abilities which in turn can affect student learning [18]. The construct of teaching self-efficacy has been divided into two major sections- personal teaching efficacy that relates to the teacher’s level of confidence with regards to his/her teaching abilities, and general teaching efficacy that refers to a generalized belief on the ability of teaching difficult children [17]. These two sections together influence the teacher's beliefs in his/her ability to positively affect students' learning outcomes.

Instrument Literature review

It is abundantly clear that teaching self-efficacy is extremely important in the domain of education and this realization has led to the development of multiple instruments over the years designed for its measurement. Some of the notable instruments developed during the formative years of teaching self-efficacy research include the Teacher Efficacy Scale (TES) by Gibson and Dembo [19] and Ashton vignettes by Webb and Ashton [20]. The TES instrument which was extremely popular, was a 30-item scale yielding two factors (Personal Teaching Efficacy - PTE for assessing self-efficacy and General Teaching Efficacy - GTE for assessing Outcome Expectancy) consistent with the RAND framework- interpreted via Bandura's Social Learning Theory. However later studies [21-24] of this scale found multiple inconsistencies and theoretical problems, thereby calling into question the veracity of findings based upon its results. Another teaching self-efficacy scale - a 30 item instrument was developed by Bandura [9]. Hoy and Woolfolk [25] developed the Ohio State University Teaching Scale based on numerous teaching skills measuring a teacher's capabilities in a host of domains like managing the classroom, evaluating students' performance, using radical learning methodologies aimed at fostering a sense of cooperativeness amongst the students; this scale consisted of 32 items. Another interesting scale was developed by Dellinger *et al.* [26] known as the TEBS-Self scale; this was an instrument for a more practice-oriented applications. The instrument that is used for this study is the T-STEM (Teacher- STEM), developed by the Friday institute at North Carolina State University, created specifically for the purpose of determining a teachers' level of confidence and self-belief in teaching STEM subjects, outcome expectancies and STEM specific career awareness [27].

STEM Teaching Efficacy

While in the beginning, the teacher's level of self-efficacy was considered with respect to general aspects, targeting all teachers without discriminating in terms of the subject area, it was evident the self-efficacy of the teacher can vary significantly dependent on the subject area. Focusing solely on STEM subjects, Brand and Wilkins [28] observed that effective implementation of STEM education was dependent on teachers' self-efficacy levels. Nadelson *et al.* [29] found that teachers' levels of confidence and efficacy associated with teaching STEM subjects increased with increase in their mathematics and science knowledge. Specific measures of self-efficacy have been developed for mathematics [30], science [31], technology [32] and engineering [33]. Integrating STEM education at K-12 levels is viewed as a way for the US to remain globally competitive [34]. But, while teaching self-efficacy has been explored in details for teaching science, mathematics and technology, teacher's self-efficacy beliefs have been rarely explored in the context of STEM integrated K-12 education and previous studies conducted in this area have mainly concentrated on postsecondary settings instead of focusing on junior high and high school levels. Of the limited set of instruments that have been developed for this purpose, there exists the TESS scale to measure K-12 teachers' self-efficacy in engineering, concentrating on five distinct factors-engineering knowledge, instructional, engagement, outcome expectancy and disciplinary self-efficacy. The lack of past studies in this particular spectrum represents a huge research gap which this paper tries to fill. Therefore, the objective of this paper is to investigate on the self-efficacy beliefs of teachers with respect to STEM integrated K-12 education.

Research Design
For the purpose of this paper, the research design employed pretest and posttest assessments on a group of high school teachers who attended the E3 enrichment program. The teachers, five in total, were first surveyed on their professional beliefs relevant to manufacturing technology. Next, the teachers were assessed using the T-STEM for determining how each of them judged themselves on areas associated with teaching self-efficacy – Technology teaching efficacy and beliefs, technology teaching outcome expectancy, student technology use, technology instruction, 21st century learning attitudes and STEM career awareness, in all consisting of 63 questions. The teachers were then asked to participate in the Enrichment Experiences in Engineering (E3) Program at Texas A&M University. The E3 program was offered by Texas A&M University's College of Engineering as a two-and-a-half-week-long summer residential research experience at Texas A&M's College Station campus. The participants were secondary level mathematics, science, and Career and Technical Education (CTE) teachers from Texas. The mission of the program was to "excite, empower and educate teachers about engineering so that they in turn will excite, empower and educate students and any other teachers they come in contact with each day." The objective of this program was to provide the high school teachers with insight into engineering research, develop engineering projects for classroom implementation and increase their awareness of the career opportunities present in engineering. After partaking in the program, the same set of teachers were again asked to fill out the T-STEM self-efficacy questionnaire. The key research question that was developed is as follows-

RQ: Do the teachers' perceptions, self-efficacy beliefs and outcome expectancies change significantly after partaking in the E3 program?

H_0: The null hypothesis- The teachers' perceptions, self-efficacy beliefs and outcome expectancies do not change significantly after partaking in the E3 program.

To answer this question, the above null hypothesis was formulated and the scores provided by the teachers, pre and post-enrichment, were compared using statistical tests to determine whether the program was successful in improving the teachers' attitudes and self-efficacy beliefs.

Instrument Description
The T-STEM instrument was developed in 2012 by The William and Ida Friday Institute for Educational Innovation at North Carolina State University [27]. The instrument itself is a survey questionnaire consisting of 63 total questions divided into 7 different sections as described below in Table 1. Each of the seven sections of the survey was adapted from other well-known surveys, thereby making this T-STEM instrument quite robust and comprehensive. The response to each question was recorded on a five-point Likert scale consisting of the following choices- Strongly Disagree, Disagree, Neither Agree nor Disagree, Agree and Strongly Agree. Apart from filling out the T-STEM survey, the teachers were also asked to fill out two separate sets of questions- one during the pre-enrichment survey, asking the teachers about their beliefs regarding manufacturing technology and another during the post-enrichment survey, asking them about their experiences in the E3 program. Furthermore, the teachers were also asked to identify their gender, age, education level, employment status and race/ ethnicity.

Table 1. T-STEM instrument sections

Section	Section name	Section description
A	Technology Teaching Efficacy and Beliefs	Belief in technology teaching ability
B	Technology Teaching Outcome Expectancy	Belief in the extent to which effective teaching affects student learning in technology domain
C	Student Technology Use	Frequency of student technology use during instruction
D	Technology Instruction	Frequency of using technology instructional practices
E	21st Century Learning Attitudes	Attitude towards 21st century learning
F	Teacher Leadership Attitudes	Attitude towards teacher leadership activities
G	STEM Career Awareness	Awareness of STEM career prospects

(Adapted from Caliendo, 2015)

Data Analysis

The following is a brief description of the data analyses that has been conducted in this paper. The responses to the question were analyzed to draw useful insights into the teachers' beliefs regarding manufacturing technology prior to the E3 program workshop and their feedback after partaking in it. The T-STEM survey scores were then converted to a numerical scale ranging from 1 to 5. The pre and post-enrichment scores were then compared using a relevant statistical test to determine if the teaching efficacy beliefs of the teachers improved after completing the E3 program, differentiating of the different sections of the T-STEM survey.

Of the five teachers who participated in this study, three were females while two were males. In terms of race/ ethnicity, two of the respondents identified themselves as white, two as Hispanic/Latino and one as Asian. Two of the respondents were under 50 years of age, while the remaining three were over 50. Table 2 provides the detailed demographic summary.

Table 2. Demographic information

Respondent	Gender	Age	Race/Ethnicity
1	F	33	White
2	F	57	Hispanic or Latino
3	M	52	Hispanic or Latino
4	F	25	White
5	M	55	Asian

Figure 1 is a histogram of the median scores given by the participating teachers prior to starting the E3 program. As can be seen from the figure, the median score recorded does not fall below 3 for any of the seven sections. For the Section F especially, which incidentally is a measure of the attitude towards teacher leadership activities, all respondents gave a median score of 5 for this section. Figure 2 is the histogram of the scores given by the participants after completing the two-and-a-half-week E3 program. Comparing this figure, section by section with Figure 1, some key differences immediately stand out. For example for sections A (Technology Teaching Efficacy and Beliefs) and C (Student Technology Use), the scores provided seems to have improved dramatically post-enrichment. Moreover, for section B (Technology Teaching Outcome Expectancy), none of the teachers had a median score of 3 post-enrichment, unlike their pre-enrichment response. These results seem to indicate that the E3 program was successful in improving the teacher's efficacy beliefs and attitudes. However, further hypothesis tests need to be carried out in order to determine whether the improvement in scores is statistically significant, which the next objective of this study as is discussed below.

Table 3 provides a summary of the mean scores provided by the teachers to the T-STEM questionnaire. The 'Pre' columns refer to the scores given by the teachers prior to participating in the E3 program while the 'Post' columns refer to the scores provided by the teachers after completing it.

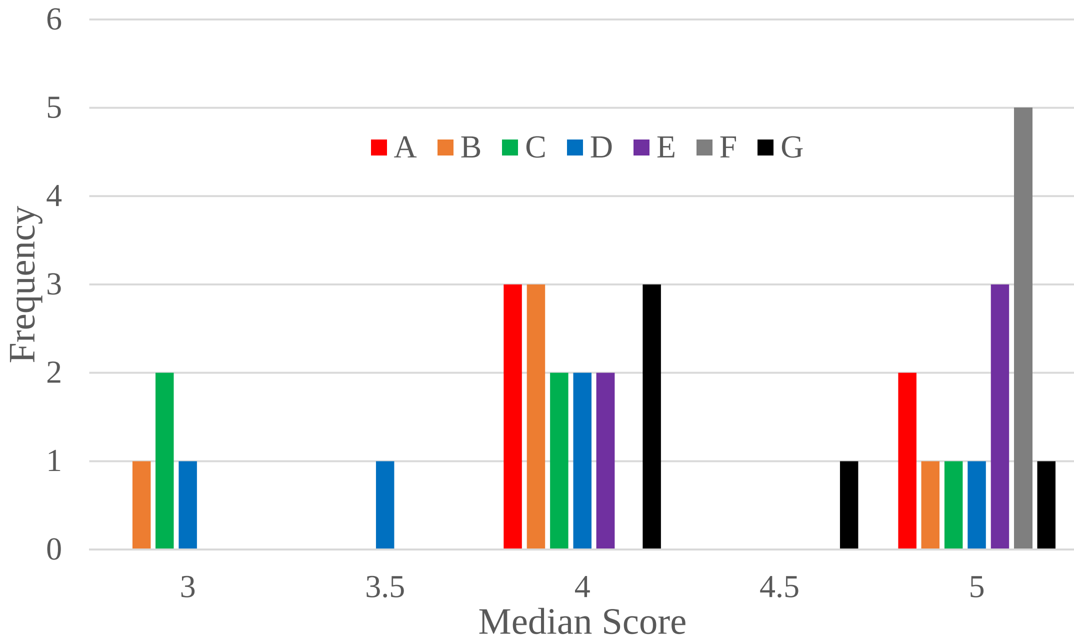

Figure1. Histogram of median scores pre-enrichment for each T-STEM section

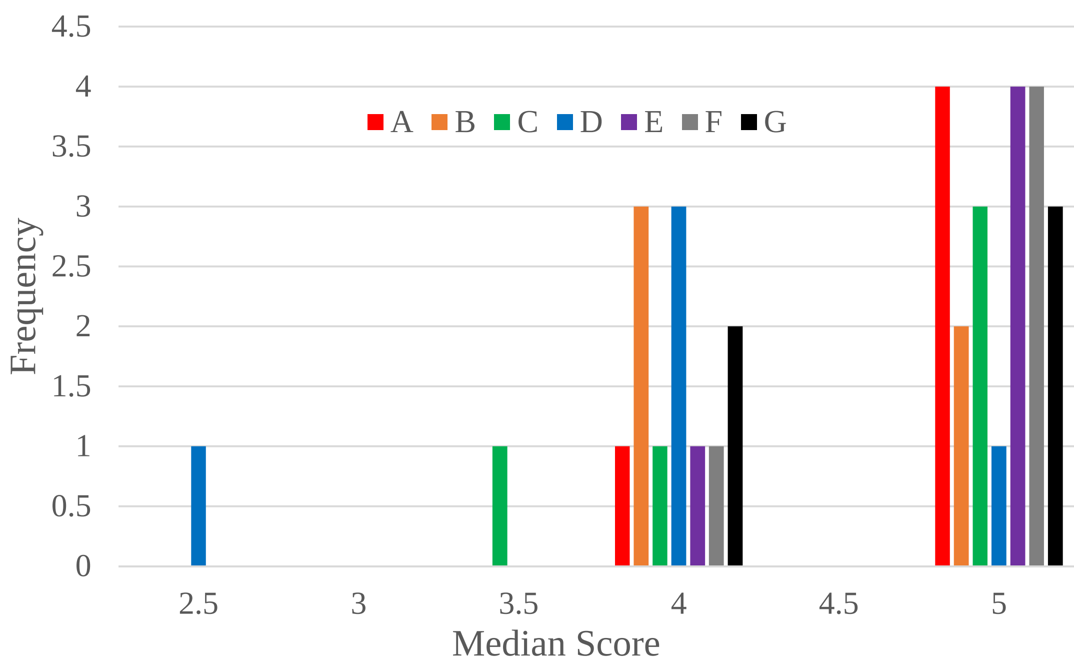

Figure 2. Histogram of median scores post-enrichment for each T-STEM section

Table 3. T-STEM score summary

	A		B		C		D		E		F		G	
Teacher	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
1	4.09	4.82	4.11	4.56	3.25	5.00	3.50	4.36	3.55	4.64	4.67	5.00	4.50	5.00
2	4.73	4.73	4.89	5.00	4.75	5.00	5.00	4.93	5.00	5.00	5.00	5.00	5.00	5.00
4	3.73	3.82	3.44	3.33	2.88	3.25	3.07	3.00	5.00	5.00	4.83	5.00	3.50	3.75
3	4.64	5.00	3.56	4.00	4.13	5.00	4.21	4.00	4.00	5.00	5.00	5.00	4.00	5.00
5	3.91	4.36	4.00	3.89	4.00	4.00	4.14	4.14	5.00	4.09	5.00	4.33	4.00	4.00
MEAN	*4.22*	*4.55*	*4.00*	*4.16*	*3.80*	*4.45*	*3.99*	*4.09*	*4.51*	*4.75*	*4.90*	*4.87*	*4.20*	*4.55*

Table 4. P-values for Wilcoxon signed-rank test

Section	**A**	**B**	**C**	**D**	**E**	**F**	**G**
P-value	**< 0.001**	> 0.2	**< 0.001**	> 0.2	> 0.2	> 0.2	> 0.2

From the table, it seems that the scores provided by the teachers across all sections post-enrichment have improved as compared to those provided pre-enrichment, suggesting that the E3 program was successful in attaining its objective. The only exception to this seems to be Section F, but there the difference is extremely negligible.

Manufacturing Beliefs

Prior to taking part in the E3 program, the teachers were asked to complete two surveys- a) a pre-test assessment using the T-STEM instrument and b) a questionnaire regarding the teachers' beliefs regarding manufacturing. The respondents a) disagreed that manufacturing is more art than science, b) disagreed that manufacturing is limited to automotive and electronics, c) disagreed that manufacturing is too early to introduce to high school students, d) strongly disagreed that manufacturing is a dirty job which is why it is difficult to attract high school students, e) strongly disagreed that manufacturing jobs are limited to Texas, f) disagreed that manufacturing concepts are difficult to fit in high school curriculum, g) disagreed that the workshop may be too technical, h) disagreed that they will have enough resources to include the training module to high school students and i) strongly disagreed that students need to wait till college to learn about manufacturing.

Workshop Experience

After completing the E3 program the teachers were asked to fill out a feedback survey alongside completing the T-STEM posttest assessment. On average, the respondents a) strongly agreed (all) that the workshop materials were hands-on and easy to visualize the process, b) strongly agreed (all) that they learned a lot about high value manufacturing, c) strongly agreed that their perception about manufacturing changed after this workshop (exception- Respondent 4 who neither agreed nor disagreed), d) strongly agreed that manufacturing is a science, therefore fitting well with their STEM course (exception- Respondent 5 who neither agreed nor disagreed), e) strongly agreed that the manufacturing curriculum can be introduced to high school students and f) strongly agreed (all) that they would like to attend similar workshops to enhance their knowledge. Overall, the responses provided the teachers indicate that their experience with the E3 program was extremely positive.

Wilcoxon Signed-rank Test Results

In order to determine whether the difference in scores provided pre and post-enrichment were statistically significant, the Wilcoxon signed-rank test was performed on the data. The reasons why this particular test was chosen to compare the scores are as follows- a) there are only five pairs of observations for every section of the T-STEM survey thereby constituting a very small sample size. Since it is extremely difficult to ascertain the distribution of the data with such a small sample size, parametric tests are thus discarded as they require an underlying assumption regarding the distribution of the data. Thus non-parametric tests are the only possible way to test these results; b) each pair of observation refers to a pretest and a posttest survey conducted on the same person, thereby implying that the responses in the pair are not independent but in fact, correlated. Since the Wilcoxon Signed-Rank test is a non-parametric test ideally suited for correlated data, it is used for the purpose of this study and preferred over other competing techniques like the Mann-Whitney test. The p-values obtained after performing the Wilcoxon signed-rank test on each of the seven sections of the T-STEM survey, comparing the mean scores pre and post-enrichment, are detailed in Table 4. According to the results, the p-values were found be <0.05 (95 percent confidence level) for two sections – A and C, thereby suggesting that the difference in mean scores was statistically significant for those two sections. These two sections correspond to Teaching Technology Efficacy and Beliefs, and Student Technology Use, respectively. The implication is that the teachers' efficacy beliefs regarding technology improved significantly after they completed the E3 program, thereby making the program a success. Furthermore, after participating in the program, their attitudes regarding how frequently students should be using technology to aid their learning process also improved. While information regarding the age, gender and race/ethnicity of the teachers was also present, further analysis, differentiating on the aforementioned factors could not be conducted due to insufficient sample size.

Conclusion

The objective of this paper was to evaluate the impact of the E3 program on the participating teachers and determine whether it resulted in improving their technology self-efficacy beliefs and attitudes, and STEM career awareness. For that purpose, the teachers were asked to complete pre-test surveys (prior to participating in the E3 program) and post-test surveys (after completing the E3 program) based on the T-STEM instrument. Their scores were then compared using a Wilcoxon Signed-Rank test to determine if the mean response changed. Since the T-STEM survey consisted of seven sections, the test was carried out for each of the sections individually. It was concluded that for two sections, A and C, the post-test response was significantly better than the pretest ones. This implied that the technology teaching self-efficacy beliefs of the school teachers improved significantly after participating in the E3. Furthermore, their attitude towards the frequency of allowable student technology use also improved. Apart from being able to improve the teachers' attitudes and efficacy beliefs, the E3 program was also given an extremely positive feedback by the participating teachers. They all agreed that their perceptions regarding manufacturing changed significantly after completing the E3 program and expressed their eagerness towards attending similar workshop programs in the future for enhancing their knowledge. The key limitation of this study was the insufficient sample size, which prevented us from conducting further analysis of the results. Therefore, exploring the difference in mean responses across various differentiating factors like race, ethnicity and age can be thought of as the future scope of this particular study.

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