An Advanced Technological Education Project for High Value Manufacturing: Lessons Learned

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Abstract
Projects rarely go according to plan, but this is especially true of those that involve multiple institutions and have a significant degree of complexity associated with them. This work relates the experiences an Advanced Technological Education (ATE) project around high value manufacturing. The project was a collaboration with a Texas A&M University and Houston Community College. The project comprised three main aspects: 1) the development of a certificate program in high value manufacturing; 2) offering professional development to working professionals in the area of high value manufacturing; and 3) educating teachers about advanced manufacturing with a goal of recruiting their students into manufacturing careers. This work describes the lessons learned through each of the project aspects.

The design of the High Value Manufacturing Certificate Program required close collaboration between both institutions. The issues that arose during this development process included personnel turnover, approval timelines and processes, and agreement on the course content. The authors will relay how they navigated these issues to get the program created and approved.

The creation of the professional development program did not involve the community college directly, but was very dependent on recruiting participants. This recruitment proved to be more difficult than the project team expected. The targeting of the professional development program and the development of the curriculum will be discussed. The authors will also highlight the delivery changes they implemented over the two years of the offerings based on participant feedback.

The final aspect of the project is the teacher experience with advanced manufacturing. Hosting teachings and determining what content and activities they experience is a somewhat daunting task. The use of an existing University Program and the selection of collaborating faculty will be discussed. Overall, the lessons learned from this project can be an opportunity for new ATE principal investigators (PIs) to learn from the authors' experiences. It can also help potential ATE PIs craft more realistic and practical proposals.

1. Introduction

The Advanced Technological Education (ATE) program of the National Science Foundation promotes the education of technical personnel through partnerships among academic institutions and industry. The ATE project discussed here details a partnership between Texas A&M University and Houston Community College. The project focused on high value manufacturing in the oil and gas industry. Given the interactions among different organizations and the various aspects of the projects, ATE projects are likely to be more complex than traditional NSF research projects. This work details some of the lessons learned from the various activities associated with this ATE project.

The project discussed was conceptualized during 2014 when a boom in the energy sector was increasing manufacturing activities in Texas. This created a need for a skilled workforce to meet these demands. The type of equipment used for oil and gas exploration and production (E&P) is often high value; the manufacturing of this type of equipment and tooling requires a workforce with multifaceted skills. In high value manufacturing, a single component can be valued at tens of thousands of dollars. Therefore, personnel must have expertise in various areas to meet customer demand under exacting time and quality constraints. A plan was developed to prepare technicians with skills such as: design, materials, manufacturing processes, project management, quality, and logistics and supply chain management. This plan took the form of a certificate program at the Houston Community College. Courses in the certificate program could be used for some of the requirements of an Associates of Applied Science degree in Manufacturing Engineering Technology. The program could also lead to a Bachelors of Science degree in Manufacturing and Mechanical Engineering Technology at Texas A&M.

The need for additional STEM personnel has been [1-3] well established. This is especially true in manufacturing which has in the past had negative perceptions associated with it being a low-skill, dirty, dangerous, and insecure form of employment. To counter these perceptions among potential manufacturing technicians, a residential program to provide research experiences in manufacturing for high school teachers was developed. These teachers came to the Texas A&M campus for three weeks and were paired with research faculty to work in their labs. As part of the experience, they were tasked with developing lessons that they would take back to their schools to promote the concept of modern manufacturing.

The first two aspects of the project related to training aspiring technicians and creating demand for training. The third part of the project focused on providing professional development for existing technical personnel through continuing education workshops. These continuing education workshops were offered in Houston and consisted of one focused on Manufacturing Operations Excellence and one focused on Manufacturing Quality. These workshops were aimed at technical level technical personnel. However, more senior and extensively trained personnel attended as well. Throughout these various aspects of the project, some successes were achieved, some alterations to the initial plan were made, and many lessons were learned. The goal of this work is to communicate that information to other current and aspiring ATE PIs.

2. Literature Review

The Advanced Technological Education program is an initiative of the National Science Foundation in response to Scientific and Advanced Technology Act (SATA) of 1992 passed by the United States Congress to help meet the nation's need for skilled technological workforce at the technician level [4]. The technological domains include, but are not limited to, manufacturing, energy and the environment, agriculture and biotechnology, engineering technology, information technology, nanotechnology and cyber security [5]. The primary goal of the program is to develop a skilled workforce who can contribute to nation's prosperity and security [6]. While the primary target for this program is to support community colleges to develop both credit and non-credit program in the above-mentioned areas, many community colleges also partner with four-year institutions in their efforts. In this section, we briefly describe few prior ATE projects, funded by NSF, that have been successful in delivering to the mission of the ATE program.

As mentioned earlier, several two -year and four-year intuitions across the United States have benefited from this program. For example, Craft et al., [7] describe that Aims Community College and Arapahoe Community College implemented a problem-based learning methodology in the curriculum to expose technicians to real world ICT (Information & Communication Technology) problems in the classroom as a part of their Colorado ATE partnership. This effort significantly improved the scores of the students in an employability test conducted after they completed the program [7]. Another ATE project executed by J.F. Drake Technical college and its partner institutions Michigan Technological University, University of New Mexico and Chandler-Gilbert community college supported updating of electrical and computer technology curriculum, primarily to prepare technicians to work in cutting edge reconfigurable electronic technology. This project substantially updated the digital logic courses at participating universities and colleges which resulted in hundreds of students joining the technician workforce every year [8]. Likewise, the ATE program also helped create a new program on photonics and laser technology at Baker college in fall 2013 in an attempt to prepare skilled technicians for the growing photonics industry across the country [9]. This program successfully implemented a new course curriculum in photonics including optics and photonics laboratory. This has increased student enrollment year by year thereby contributing to the growing portion of the skilled workforce in the photonics industry [9]. The ATE project on "Technical Education for Rural Community" at Hopkinsville Community College has improved math coursework for advance manufacturing technicians. This project addressed the deficiency of math foundations for the technicians by updating their coursework matching the requirements from the industry [10].

Furthermore, the program funds a few large initiatives each year as ATE Centers. They generally have a large budget and scope of the work. For example, the FLATE (Florida Advanced Technological Education) Center collaborated with industrial partners and department of education to develop a coursework which compiles the requirements of industry and is uniform across 11 colleges in Florida. This coursework incorporates modules which allow the students to be a certified production technician, a part of NAM's skills certification system [6]. Similarly, the ATE funded iGETT-RS (Integrated Geospatial Education Technology Training-Remote Sensing) program has improved the skill and knowledge levels of the 76 GIS (Geographic Information Systems) instructors by updating the coursework in remote sensing and conducting summer workshops. One of the objectives of the FLATE center is to enhance the quality of geospatial workforce by training the instructors. This program has been highly commended as a role model [11].

Table 1 shows some additional sample ATE projects funded by the NSF which have been able to make a positive impact on technician education [12-19]. Clearly, the projects span across a variety of domains accomplishing the goal of developing a skilled workforce which is critical for a nation to be competitive in the world. Berger et al., [10] suggest that there are three important contributing factors for ATE's success: 1) merit review policy of NSF helps to choose the best valued projects; 2) industry involvement in curriculum development and other project related activities; and 3) alignment of program curriculum with industry expectations. The academic programs developed with the help of ATE grant includes both traditional and distance education programs [20]. This paper discusses one such ATE project in high value manufacturing.

Table 1: Sample ATE projects and centers and outcomes

No	Project Name	Institution	Topic Area	Significant Outcomes	Reference
1	Expanding the National Center for Welding Education	Lorain County Community College	Welding Engineering	Developed certification courses for high schools and community colleges	Polanin [12]
2	University, Community College and Industry Partnership: Revamping Robotics Education to Meet 21st Century Workforce Needs	Michigan Tech and Bay de Noc Community College	Robotics	1) Revamped Robotics Curriculum at Michigan Tech and Bay de Noc Community College, 2) Developed "RobotRun" Robotic Simulation Software, and 3) Modeled Robotics Curriculum for K-12 Teachers and Hands-on Training Sessions for High School Students.	Aleksander et al. [13]
3	Marine Advanced Technology Education Support Center	Monterey Peninsula College	Marine Technology	1) Increased number of students participating in the MATE at-sea technical internship program, and 2) Developed an international remotely operated vehicle (ROV) technician competency program	Sullivan et al. [14]
4	Community College Undergraduate Research Initiative (CCURI): Creating a culture of change	Finger Lakes Community College	Education	1) Developed a prototype set of data and problems set for undergraduate curriculum, and 2) Created Data Investigation Builder (DIB) for professors,	McDonnell et al. [15]
5	Creating Pathways for Big Data Careers	Education Development Center	Big Data	1) Created Middle-Skill Big Data-Enabled Specialist (MSBDES) methodologies, and 2) Worked on an assessment framework to assess student proficiency in big data	Joseph and Malyn-Smith [16]
6	Troubleshooting and Safety Simulator for Wind Turbine Technician Education	Purdue University	Safety Simulator	1) Designed virtual 3D wind turbine model, 2) Created virtual simulator using Unity3D, and 3) This model is used to augment existing technician training	Moreland et al. [17]

7	Optics & Photonics INnovation-OPT IN!	Monroe Community College	Optical Industry	1) Assessed the gap between demand and supply of technicians that work in optical manufacturing industry, and 2) Proposed Optical Systems Technology program to meet the industry demand with AAS degree at MCC.	Alexis [18]
8	Advancing Photonics and Laser Technician Education in Michigan	Baker College of Flint	Laser & Optical Fiber	1) Developed Photonics and Laser Technology program curriculum, and 2) Streamlined two-year Photonics and Laser Technology Program at Baker college including lab equipment.	Sala [19]

3. Project Summary

As noted above, the project consisted of three major activities. To provide context for the outcomes and the lessons learned, these are summarized below.

Enrichment Experiences in Engineering

To help recruit the next generation of high value manufacturing technicians, a group of high school teachers were invited to attend the Enrichment Experiences in Engineering (E3) program. This two-and-a-half-week program provided teachers with the opportunity to work in labs with Texas A&M faculty doing manufacturing research. The teachers, 11 in total, were secondary level mathematics, science, and Career and Technical Education (CTE) teachers from Texas. 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 in general, and manufacturing specifically.

In addition to their laboratory experiences, the teachers also had general professional development activities that covered engineering design, educational best practices, and networking with other participants in addition to master teachers. Master teachers were successful prior participants in the E3 program. As part of the program, each teacher had to prepare a lesson that they would take back to their school to deliver during the following semester. They also had to deliver a presentation and a poster detailing the research that was being done in the lab they were part of during the program.

High Value Manufacturing Certificate

Work on the High Value Manufacturing certificate program began as soon as the grant was funded in the summer of 2015. In the interim period (between proposal submission and funding), several personnel changes at HCC took place. There was a change in the Dean at the Manufacturing Center of Excellence (that housed the program) and one of the HCC administrators that served as a co-PI from HCC was reassigned. One of the Texas A&M co-PIs also left the university.

The initial meetings in the summer and fall of 2015 focused on forming a consensus as to what content was necessary for the to be developed courses, finding any existing courses that could be slightly altered, and pulling together the necessary documentation for the program. While the certificate approval plan was known and included in the proposal, the actual certificate approval process took significantly longer than planned. The combination of personnel turnover and other unforeseen delays resulted in the actual curriculum not being approved until fall 2017. The curriculum is shown in Table 2. The courses develop specifically for the program are bolded. In addition to developing new course, some courses were designated to be competency based [21] in nature.

Table 2. Proposed HVM Curriculum

Course Number	**Course Number**	**Credit Hours**
	Semester 1	
ENTC 1347	Safety and Ergonomics	3
MATH 1314	College Algebra	3
MCHN 1302	Print Reading for Machining	3
MCHN 1338	Basic Machine Shop I	3
PTRT 1301	Introduction to Petroleum Industry	3
	Semester 2	
MCHN 1308	Basic Lathe	3
MCHN 1313	Basic Milling Operations	3
INMT 1345	Computer Numerical Controls	3
INMT 1371	**Materials and Applications**	**3**
PTRT 1470	Petroleum Data Management I – Exploration	4
INCR 1302	Physics of Instrumentation	3
	Semester 3	
PTRT 2370	Petroleum Operations	3
INMT 1343	**Computer Aided Design/ Manufacturing (CAD/CAM)**	**3**
INMT 1372	**Quality and Assessment**	**3**
INMT 2370	**Project Management**	**3**
INMT 1373	**Machine Shop Logistics**	**3**

Unfortunately, just as the program was supposed to come online in fall 2017, Hurricane Harvey hit Houston and caused a significant amount of damage and disruption. HCC was closed for the beginning of the semester and potential students had to deal with the disruption that the storm caused to their lives. It should also be noted that when the proposal was being conceptualized in 2014, the price of oil was well over $100/barrel. Once the proposal was funded, the price of oil had dropped precipitously. While some of the classes associated with the program were being offered as part of other programs (see Figure 1), the courses distinctly created for the program were not offered until the fall of 2019.

Figure 1. Photo of High HCC Instructor and Students

Continuing Education

To improve the knowledge and skills of existing workforce in oil and gas industry, four continuing sessions (two each in summers of 2018 and 2019) were conducted in the various topics of high value manufacturing. The broad theme of the two sessions included: Manufacturing Operations Excellence and Manufacturing Quality Excellence. Table 3 provides the description of the topics covered in the continuing education sessions.

Table 3: Continuing education modules and topics

Session	Modules	Topics covered
Manufacturing Operations Excellence	Inventory Management Best Practices	Inventory classification Inventory costs and economic order quantity Re-order point and safety stock
	Manufacturing Operations Management	Production cost-assessment and management Materials requirements planning Minimizing manufacturing waste and non-value-added time
	Quality Management Best Practices	Assessing supplier quality, assessing the cost of poor quality.
Manufacturing Quality Excellence	Defining and Measuring Quality	Basics of Quality Cost of poor-quality during measurement and analysis
	Non-Destructive Evaluation	Identifications of manufacturing defects Types and selection of appropriate NDE methods Analysis and interpretation of data
	Statistical Process Control	Statistical Process Control Process Capability Analysis

These topics were selected based on the discussion with industry advisory board at Houston Community College. Further, all four sessions were offered in Houston to attract large number of industry participants. Altogether, 46 industry professionals attended in 2018 and abut 30 professionals attended those sessions in 2019. The companies represented in the continuing education sessions were original equipment manufacturers, suppliers, and distributors from oil and gas industry. It may be worth mentioning that the original continuing education plan was revised from three days to two days based on industry advisory board's feedback.

4. Outcomes and Lessons

Enrichment Experiences in Engineering

As noted above, the E3 program provided research experiences for 11 teachers over the summers of 2017 and 2018. By using the E3 program infrastructure, the program was able to recruit a diverse set of participants. Over 80% of participants were under-represented minorities in STEM. There were almost an equal number of male and female participants. To examine the impact of these experiences on the teachers' views of STEM in general, and manufacturing in particular, a pre- and post- research design model was used. The effectiveness of the program was analyzed by employing the validated T-STEM instrument, before and after the program. The T-STEM instrument was developed in 2012 by The William and Ida Friday Institute for Educational Innovation at North Carolina State University [22]. The instrument itself is a survey questionnaire consisting of 63 questions divided into 7 different sections: Technology Teaching Efficacy and Beliefs, Technology Teaching Outcome Expectancy, Student Technology Use, Technology Instruction, 21st Century Learning Attitudes, Teacher Leadership Attitudes, and STEM Career Awareness. 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- pre and post E3 program about their beliefs regarding manufacturing technology. The survey also included demographic information including the education level of the participating teachers.

Overall, the participants increased in all aspects of the T-STEM with the exception of a small decrease in 21st Century Learning Attitudes. Preliminary data from this program is shown in a previous paper [23]. There were also significant increases in the positive attitudes associated with manufacturing. Overall, this portion of the project went almost exactly as it was proposed. A few key lessons can be drawn from this project aspect. First, the use of existing institutional resources meant that the project team did not have to organize the experiences or recruit the teachers. The project team was only responsible for recruiting participating faculty. For this aspect, having project funds available to pay for teachers research supplies (e.g., materials for samples) helped convince faculty that hosting the teachers would not be a drain on their resources. The E3 program also ensured that the educational units that the teachers developed were paced over the course of the program. Teacher remuneration was also phased such that the teachers did not receive the last portion of their stipend until they had provided their implemented lesson plans and all necessary project data. These features helped ensure the success of this project aspect.

High Value Manufacturing Certificate

The development of the curriculum for the High Value Manufacturing Certificate required negotiation within the faculty of HCC, but also collaboration with the group from Texas A&M. Given that some of the courses would be accepted as equivalent courses at Texas A&M, certain topics and course material had to be assured. These included aspects related to the course laboratories. At the same time HCC faculty wanted to ensure that the courses were appropriate for their students and would provide the skills desired by employers (for those who wanted to finish with the certificate and not pursue advanced education). Both groups agreed on the importance of authentic industry examples in the developed curriculum [24]. This coordination required significant time and meetings. One lesson learned from this experience is that these coordination meetings and the necessary time should be explicitly incorporated in the curriculum development timeline. Another issue that the project team did not foresee was the difficulty in getting all of the participants on the same learning management system (LMS). The Texas A&M team had to get access to the HCC LMS and provide feedback to the instructional designer. Fortunately, the HCC instructional designer was available to the project team and provided a high level of service. For future such projects, budgeting an instructional designer for such activities might be beneficial.

As noted above, there was a significant delay in the approval of the High Value Manufacturing Certificate Program. Once the program was approved and ready to be offered, recruitment became a challenge. Some issues were due to Hurricane Harvey, but the late approval did not allow for the previous spring and summer to be used for recruitment. The turnover in personnel and the decline in the oil price also did not help. Currently recruitment efforts are underway to get a sustainable number of students into the program. Future ATE projects should explicitly think through any economic dislocations and their impact on student numbers as well as how to mitigate that impact.

Continuing Education

As mentioned earlier, both continuing education sessions received a good participation (above 75 participants in total) from industry. While 2019 data analysis report from the project external evaluator is not available at the time of this reporting, 2018 sessions data showed that the professional development sessions were well received. The course evaluation conducted at the end of each session included four aspects of the program, which are: course design and organization, hands on and relevant, how much they learned, and interest in similar sessions in the future. The average rating was above 4.0/5.0 across all topics in both manufacturing excellence session and manufacturing quality excellence session [25]. That being said, average score for the non-destructive evaluation (NDE) module in Manufacturing Quality Excellence session was slightly lower (approximately 3.75/5.0) than those for other modules. The lower score for NDE could be explained due to the larger amount and more technical nature of the learning materials as reflected in the participant's open-ended comments. In overall, the higher than target (3.5/5.0) course evaluation scores demonstrated that the professional development sessions were able to meet course objectives in terms of renewing/enhancing participants' HVM skills set.

5. Conclusions

The National Science Foundation's Advanced Technological Education Program was created to educate technician level professionals in various areas. The areas cover a wide range of STEM topics. Given the need to meet some industry and technical demands, these projects often involve more than one institution and target different populations. The project discussed in this work did both. In addition to targeting potential technicians with the certificate program, the project also worked with existing professionals for the continuing education program, and high school teachers for the Enrichment Experiences in Engineering (E3).

The coordination of activities required between the two educational institutions took longer than anticipated and required more effort that initially envisioned. Future ATE projects should make sure that their timelines consider such coordination when developing their timelines. The economic issues associated with the oil and gas industry and personnel turnover also adversely affected recruiting for the certificate program. Hurricane Harvey significantly limited the recruitment opportunities during the first semester of the approved program and also meant that some potential students did not continue their education at HCC. New programs should ensure significant time to recruit participants as well as developing continuity plans for how to deal with any staff or administrative turnover. The success of the E3 program was facilitated by the use of existing institutional resources and the ability to offer faculty a no cost option to support the program. Future ATE projects should ensure that any hosting activities do not require a financial commitment from the participating faculty. Finally, the importance of offering focused and value-added professional development should be stressed. The original plan for the continuing education program was broader and less focused. However, industry feedback showed that shorter more focused program was preferred. Even a low-cost program requires that employers give up their employees' time; this requires that the employees be provided skills that are directly beneficial to the employer and that the program does not take the employee away from work for too long. The authors believe that these lessons will be of value to ATE project proposers and personnel.

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