



Pipeline for Progress: Multi-Level Institutional Collaboration for Engineering Education

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BT-ATE Pipeline for Progress: A Multi-Level Educational Plan for an Emerging Industry

Abstract: A dynamic and innovative Biosystems Technology (BT) curriculum was developed at the secondary, technical college and university levels. The curriculum includes core concepts in life science, engineering, technology and mathematics focused on applications in biological systems that transition student learning and depth of understanding from one level to the next. The program was successful in educating students with increased STEM knowledge, with an emphasis on engineering content, to prepare them for the technical workforce in the growing biofuels and bioprocessing industries. A highly successful aspect of this program was implementation of Summer Teaching and Learning Institutes for pre- and inservice educators - primarily those in secondary agriculture programs in the state. The Institutes focused on the science, technology, engineering, mathematics, and agriculture of sustainable biofuels production and bioprocessing in the Southeast US. A major component of the Institutes was extensive hands-on instruction including fabrication, field and laboratory modules that utilized engineering and laboratory equipment that were provided to each participating inservice educator for use in his/her school. A total of 33 inservice and preservice educators participated in the Summer Institutes, with 19 educators participating for 2 or more years. These educators then incorporated the Biosystems Technology content into their courses of instruction. As a result, over the course of the project several thousand secondary students were directly impacted by enrollment in courses with Biosystems Technology content and more were impacted through career day and special event presentations. The response from participating educators concerning the Biosystems Technology material has been positive and transformative. Selected lessons have been implemented in SC agriculture courses and others (ie secondary biology and elementary) for four years.

A second major accomplishment was the development and implementation of a secondary pathway in Biosystems Engineering Technology by project investigators and educational advisors. The pathway was submitted by the SC State Director of Agriculture Education for inclusion in the Agriculture, Food and Natural Resources Career Cluster. The four-course pathway, consisting of Agriculture and Biosystems Science, Biosystems Mechanics and Engineering, Biosystems Technology I and Biosystems Technology II, was approved by the SC State Department of Education in 2011. The Biosystems Technology Pathway was implemented in the Lexington-Richland 5 school district in the fall of 2012 at a Career and Technical Center. The secondary educator hired to lead the implementation of the BT pathway was a participating teacher on this project.

I. Introduction

In 2007, the National Science Foundation awarded a three-year grant to the participating institutions of Clemson University, Greenville Technical College and the SC Agriculture Education Program to design and implement a three-tiered plan to prepare secondary, technical school and college students for the growing biomanufacturing/bioprocessing industry.

Industrial production of biopharmaceuticals, nutraceuticals and biofuel compounds has grown substantially worldwide in last 10 years. In the US alone, biofuel production in 2011 had reached 15 billion gallons (57 billion liters) per year.¹ As this trend continues, the need for skilled technicians, engineers and scientists to lead the development of future biomanufacturing processes and operate the current systems will continue to increase². These workers must comprehend mathematical, chemical and biological concepts as well as possess specific technical skills such as media preparation/sterilization, microbial fermentation, aeration, ultrafiltration, and process control.

At present, most biomanufacturing industries in the state train technicians on-site for the needs of their facilities. This grant proposed that because biosystems engineering (BE) curricula and instruction at the college level focus on core engineering and science concepts and skills development, incorporating Biosystems Technology (BT) into secondary and technical college curricula would be a practical method for generating a more highly educated and skilled workforce. This, in turn, would attract newer industries and, in time, provide individuals with broader employment opportunities and greater financial stability. Biosystems Technology was defined as the application of a broad range of technology and tools to macroscale biological and engineered systems in contrast to biotechnology programs that may focus on molecular-level biological science and tools. The first step was to introduce BT to students in grades 9-12 through secondary agricultural programs.

Agriculture is an important part of the South Carolina economy. Agricultural education (Ag Ed) programs are robust due to the continued interest of secondary and college students. More than 11,000 secondary students enroll in Ag Ed courses in the state each year. In the state, 108 secondary schools (including 17 Career Technology Centers) offer Ag Ed programs. The State Association of Career Technical Education Consortium offers 16 career clusters for secondary students. Ag Ed programs fall under the Agriculture, Food and Natural Resources Career Cluster. This includes agricultural production of food and fiber of which crop science and agricultural mechanization are integral. Because many agricultural crops and byproducts are used as feedstocks for bioprocessing, BT instruction is a natural extension of the career field and an optimal fit. Incorporating BT instruction with a strong experiential learning component into Ag Ed programs supplements and enhances the science and mathematics instruction the secondary students already receive. And, it provides the acquisition of technical skills needed to work in biomanufacturing companies.

II. BT ATE Project Plan

The BT-ATE project included three primary components:

- A. To develop and implement a secondary Biosystems Technology Pathway delivered through the state Ag Ed program as part of the Agriculture Food, and Natural Resources Career Cluster;
- B. To develop and implement a Biosystems Technology Certificate program at Greenville Technical College including an articulation plan with Clemson University; and

C. To develop and implement a Biosystems Technology minor at Clemson University that is available and attractive to students from other disciplines and prepare them for careers in the biomanufacturing/bioprocessing industry.

III. Development and implementation of the BT-ATE project

The discussion that follows summarizes the chronological development, implementation and revisions that occurred during each phase of the grant.

A. Year One 2008 - 2009

1. Secondary program activities

The first year involved a wide range of planning, resource acquisition, and curriculum development activities primarily focused on the secondary school component. The BT pathway was developed to consist of four core classes. Existing classes in Ag Science and Ag Mechanization were modified to include bioprocessing and sustainability principles. Two new courses (Biosystems Technology I and Biosystems Technology II) were created to focus on more advanced biological and engineering sciences and to incorporate many of the laboratory and engineering skills needed for the bioprocessing industry.

The Agricultural and Biosystems Science course was developed to include principles of microbiology, biochemistry and applied mathematics related to preserving, storing, and fermenting agricultural feedstocks to produce high value bioproducts as well as retaining information on production of food, fiber and materials.

The existing Ag Mechanization course focused primarily on power and machinery to produce food and fiber. The expanded course titled Biosystems Mechanics and Technology includes green processing technologies, and the effects of agricultural production/harvesting on the quality and quantity of feedstocks used in bioprocessing.

Biosystems Technology I is the first new course in the sequence. It focuses on key principles of microbial/biochemical kinetics, introduces mathematical modeling, energy/mass balances, heat/mass transfer, and fluid flow. All these concepts are taught in context of bioprocessing and students learn how to use appropriate data collection software for each operation.

Biosystems Technology II builds on the information and skills learned in Biosystems Technology I. Its primary emphasis is on engineering technology needed for bioprocessing including units on fluid pumping, aeration/gas transfer, primary separations, micro/ultrafiltration, heat exchange, sensors and process control and emphasizes recycling and reusing of water, heat and materials. Students learn more about each concept through hands-on laboratory experience.

Other activities included school district partnership development and initial teacher preparation during a weeklong Summer Teaching and Learning Institute conducted at Clemson University. Teacher participants from Agricultural Education programs in eight state secondary schools - both high schools and career and technology centers - were selected based on recommendations of district personnel. Three of the schools chosen were located in counties with a significant

number of an underrepresented population (Hispanics and African-American students).

The project planned for the initial group of participant teachers to be joined in two subsequent years by additional teachers. All of these participating teachers and their programs would serve as models for expansion of the secondary BT initiative throughout the state and region.

The first Summer Teaching and Learning Institute was conducted in July 2008. The Institute provided a mix of learning activities including lecture, demonstration, hands-on work including equipment and instrument training, shop-based fabrication, and practical testing of fabricated devices that could be replicated in a secondary school setting. The experiential focus of the training was designed to allow teachers to engage in hands-on learning activities to actualize their learning and to visualize how to adapt biosystems technology knowledge to existing agricultural education classes. Institute content and methods were aimed at college level standards with the expectation by project leaders that participant teachers could adjust the level of content difficulty and learning approaches to suit the academic abilities and readiness of their secondary students.

However, this was not the case. Evaluation conducted through questionnaire and focus groups of the first cohort of teachers indicated that while they understood the relevance of introducing BT instruction, they were not as comfortable with the Institute pace or level of instruction as project managers hoped. Most felt intimidated by the mathematical and scientific calculations they performed while compiling results from the laboratory experiments. None of the teachers introduced substantial portions of the BT material into their classes that year reinforcing data gathered about lack of confidence and readiness to implement emerging technologies instruction acting as a major barrier to adoption. Of the original group, six withdrew fully from the project and only two returned to the Teaching and Learning Institute the following year.

2. The Biosystems Technology Certificate Program

Greenville Technical College, part of the state's Technical College System, collaborated on the project to help expand BT instruction beyond the secondary level. Because technical colleges work closely with the secondary Career Technology Centers, there is a large pool of students who desire advanced education and/or technical training.

Greenville Technical College offers both associate degrees and certificate programs, including an Associate's Degree in Science that included a Biotechnology emphasis. And, among its 35 associate degrees were two ABET accredited programs: Mechanical Engineering Technology and Electronics Engineering Technology that emphasized production and laboratory skills. Geographical proximity was also a factor since Clemson University personnel would develop and teach supplemental BT coursework in the initial implementation.

The project collaborators worked closely to design a 37-hour Biosystems Technology Certificate focused on process engineering, applied life science and engineering technology. The certificate also includes college transfer courses for those students wanting to pursue a four-year degree at Clemson University.

3. Biosystems Technology Minor

One of the principle goals of the BT-ATE project was to establish a 15 credit hour Biosystems Technology academic minor at Clemson University. The establishment of a new minor area involves review and approval of new courses and the program of study at the department, college, and university levels.

The BT minor, when fully approved, will be available to any undergraduate student to accompany any academic major offered by the university. The minor was developed to utilize and expand on the four-year agricultural education, agricultural mechanization and biosystems engineering degrees offered on its campus.

The B.S. in Agricultural Education (Ag Ed) prepares students to become teachers and leaders in secondary agriculture education and includes courses in basic/applied science, agricultural mechanization/ technology and education courses in pedagogy, adult education, and directed teaching. The B.S. in Agricultural Mechanization (Ag Mech) is more technology-based and prepares students for technical careers in agricultural production/processing and heavy equipment industries. These courses focus on mechanization, fabrication and mechanical/electrical/hydraulic systems. However, neither of these programs includes the kind of preparation needed to support the bioprocessing/biomanufacturing industry. Interestingly, 75% of college students enrolled in Clemson's Ag Ed curriculum report having taken secondary Ag Ed courses, with close to 50% of those being women. A large number of minority students in these disciplines at Clemson University also enrolled in Ag Ed courses in secondary school.

The ABET-accredited B.S. Biosystems Engineering program (BE) is a science-based engineering curriculum integrating engineering sciences, life sciences and design. The program includes courses in biological kinetics/reactor modeling, heat/mass transport and bioprocess design. The expertise and synergy among Ag Ed and BE faculty collaborators, direct support from the State Director of Agricultural Education, as well as the link to secondary agricultural education programs and teachers across the state contributed greatly to the proposal's success.

B. Year Two 2008-2009

The lack of BT course implementation by the first cohort of participant teachers prompted a thorough review and revision of both recruitment and training methods for the second group of teachers. Project leaders listened carefully and responded to feedback from their advisors, participant teachers and project evaluators. They revised Summer Institute content to provide real-time support to teachers and a more effective introduction of the BT material.

In addition, compared to 2008, the 2009 training student binder included more in-depth information about course requirements for earning graduate credit. Project investigators added a requirement for teachers to produce a videotaped lesson as a deliverable. Other requirements for graduate credit were completion of daily surveys, creation of a professional academic poster, and design a unit plan based on a biosystems technology topic of the teacher's choice. The remaining Cohort 1 and new Cohort 2 teacher groups had the same requirements for the graduate course.

Project leaders revised teacher-recruiting procedures. State-level project staff identified potential teacher participants. Project managers conducted a live meeting for interested individuals using Adobe Connect. The meeting oriented potential second cohort teachers and introduced the grant's purpose. It outlined concepts to be presented at the Institute, and defined project-related commitments of incoming teachers and investigators. Seven highly motivated teachers became part of Cohort 2. As a result of the changes in recruiting and improved training, these seven teachers demonstrated great support for BT instruction and after the Summer Institute expressed very high levels of self-confidence for instruction.

The project investigators also expanded ongoing support and communication by adding Web-based meetings to offer convenient connection between project personnel and teachers and to facilitate peer-to-peer support among teachers. Project leaders revised the timeline for implementing BT content. Material was introduced earlier in the school year to enhance the effect of exposure to BT content on students. Earlier scheduling of school activities as part of the BT curriculum was also expected to identify any problems earlier than in the previous year and to allow remedial efforts to be taken.

Also during the second year, project managers collaborated with their technical college and university curricular colleagues to pursue formal approval of newly created courses by the relevant review bodies within the respective institutions. Plans were made to initiate both the university and technical college post-secondary aspects of the program during the project year 2.

C. Year Three 2009-2010

All Cohort 2 teachers successfully implemented BT concepts into their existing agriculture courses. Topics, type of learning activities/subject matter, and timing of BT lessons varied greatly among the schools. Teachers were able to adapt the BT program to meet their school's individual clientele. Several teachers expanded their programs in subsequent years because of increased student, school, and community interest in biosystems technology. One teacher designed two new honors courses in which BT concepts are taught and another teacher built a small biodiesel plant at the secondary school. All Cohort 2 teachers recommended participation in the BT ATE project to other teachers during the year.

Recruitment of Cohort 3 teachers was helped by greater awareness of the BT-ATE project throughout the secondary school community. Several Cohort 2 teachers received publicity for their project efforts from local media as well as from state and national FFA. One Cohort 3 teacher volunteered as a result of a presentation given by one of the project investigators at the 2009 State Association of Agricultural Educators conference, held concurrently with the 2009 BT Summer Institute. A Cohort 2 teacher recommended another teacher because he had expressed an interest in the project, and State agricultural personnel nominated 6 other teachers.

The eight Cohort 3 teachers who participated in the third Summer Institute training were an enthusiastic, knowledgeable group. They were eager to learn about the project and BT content. Evaluators noted that these teachers were friendly with Cohort 2 teachers and appeared comfortable with the rigor of Summer Institute training and the challenges involved in implementing the BT concepts into their secondary courses.

Success by Cohort 2 also led to few more modifications in Summer Institute training for Cohort 3 teachers. The Lead PI further refined training content and activities and adjusted the pace of presentation. More supporting graphics were included during lectures and teachers had more time for discussion and for questions. A session was added where Cohort 2 teachers presented results of their approaches and successes with implementation of BT material to the Cohort 3 teachers. An internal evaluation of the material presented in the Summer Institutes over the first three project years is shown in Table 1.

Table 1. Assessment of Summer Institute Activities

Activity Description	Math Concept	Technology Component	Perceived interest	Barriers
Use common laboratory tools to measure mass and volume of liquids	Density = mass/volume	Pipettors Spectrophotometer Analytical balance	Moderate	None – all tools supplied by grant
Prepare standard solutions of known concentration; measure absorbance	Dilutions; Linear regression	Spectrophotometer Analytical balance	Moderate	None – all tools supplied by grant
Produce biodiesel from variety of oils (lab scale)	Titration calculation Product yield	Burettes	High	Moderate - Hazardous compounds (methanol)
Produce biodiesel from variety of oils (pilot scale demonstration)	Flow rate calculation; heating calculation	Reactor, pumps, heat exchanger, ion exchange column	High	High - Equipment limits most; hazardous compounds
Fabricate small solar water heater; use wood, PVC pipe, acrylic	Area, length, pipe volume calculation	Shop tools (radial arm saw, drill, PVC cutting tool)	High	Low - Tools available to most ag teachers
Operate solar water heater to determine efficiency	Thermal energy balance;	Peristaltic pump, datalogger/temperature sensors	High	None – all tools supplied by grant
Measure optical density (OD), algal dry weight	Linear regression	Spectrophotometer balance, vacuum pumps/filters	Moderate	None – all tools supplied by grant
Measure transparency of lake water - Secchi Disk visibility	Graphing data (non-linear)	Secchi Disk	High	Low – Disks not supplied but could fabricate
Design, fabricate mixed (CSTR) and plug flow (PFR) reactors using acrylic sheet, tube	Volume calculation – cylinders, cubes	Chemical welding of acrylic	High	Moderate – hazardous compound; tools available to ag teachers

Table 1. Assessment of Summer Institute Activities (continued)

Conduct dye studies to study flow dynamics in mixed and plug flow reactors	Graphing; retention time calculation	Spectrophotometer; peristaltic pumps graduated cylinders	Low - Moderate	None –all tools supplied by grant
Use enzymes to hydrolyze agriculture feedstocks; measure sugars with DNS reagent	Linear regression; standard curve	Spectrophotometer	Low- Moderate	Moderate – chemicals used; waste generated
Inoculate feedstocks with yeast culture; ferment to ethanol	Calculate of ethanol content	Hydrometer to measure specific gravity, ethanol	High	Low – Hydrometers not supplied but inexpensive
Grow natural algal strains in open batch reactors	Measure pH, OD, calculate growth rate	Stir plates, pH meter/probe; spectrophotometer	High	None – all tools supplied by grant
Ferment milk to yogurt; measure temperature, pH, viscosity	Calculate viscosity	pH meter/probe Zahn cup viscometers	High	Low – viscometers not supplied but could fabricate
Design rainwater collection and irrigation piping system	Pipe sizing; friction loss calculation	Timers, sprinklers	High	Moderate – materials not supplied; costly items (rain barrel)

The initial comfort level of Cohort 3 teachers was high. They were familiar with the BT-ATE grant due to its increasing positive publicity in the secondary agriculture community, their interest in the subject area, and familiarity with Cohort 2 teachers already who had become positive ambassadors for the project.

In spite of significant reductions in research staffing due to position relocations and budget reductions, every effort was made to communicate with program participants during the academic year. Teachers received periodic emails asking about course activities and materials.

Also during Year 3, two new college-level Biosystems Technology courses were developed and submitted for institutional approval. These courses, Biosystems Technology I and II (BT 220 and BT 240) form the core of the BT academic minor at Clemson University. The learning outcomes of BT 220 are an understanding of the fundamental and applied biological and engineering concepts used in bioprocessing for biofuels and other high value compounds. Topics include bioreactor hydrodynamics, microbial growth in batch vs continuous flow reactors, and anaerobic vs aerobic metabolic pathways. The outcomes of the BT 240 course are an understanding of the basic unit operations used in bioprocessing for biofuels and other bioproducts, including fluid

mixing and pumping, heat exchange, solid/liquid separation and purification. The minor includes elective engineering and science courses from other departments. The BT courses were approved at the departmental, college, and university levels. The approval of the BT minor is pending awaiting approval by individual departments of all extra-departmental elective courses. BT 220 was taught in 2010, and was incorporated as a core requirement in the Ag Ed undergraduate curriculum at Clemson University in 2011. It was taught subsequently in 2012 and 2013 to class sizes of 15 – 20 students.

Efforts to develop and initiate BT course instruction and gain institutional approval of a certificate program in Biosystems Technology at Greenville Technical College were initially delayed by personnel changes in the biotechnology department. A no-cost one-year extension was sought and granted by the NSF to continue the project. The Industrial Biosystems Technology certificate at Greenville Technical College (GTC) was approved in 2012 . The approved 32-hour certificate (Table 2) includes key courses in Biosystems Technology I and Biosystems Technology II, as well as general education, math and biology courses. Further, three exciting new courses were developed for inclusion into the certificate program by GTC investigators– Bioinstrumentation, Control Systems, and Industrial Processes and Fermentations. This certificate will enable graduates of the program to be fully prepared to enter into the workforce for biofuels/bioprocessing industry.

Table 2. Industrial Biosystems Technology Certificate

Course	Credits
College Algebra (MAT 110)	3
Biology I (BIO 101)	4
Engineering Technology Applications and Programming (EGR 130)	3
Biosystems Technology I	3
Bioinstrumentation	3
Control Systems	2
General Organic and Biochemistry (CHM 105)	4
Biosystems Technology II	3
Introduction to Industrial Processes and Fermentation (BTN 201)	4
Probability and Statistics (MAT 120)	3
Total Hours	32

IV. External Evaluation and Results

The National Dropout Prevention Center (NDPC) conducted the evaluation of all components of the BT-ATE project. The NDPC assessed project goals and objectives as well as project activities. Researchers employed quantitative and qualitative inquiry methods to assess project implementation, progress, methodological effectiveness, and success of the project in terms of its

action plans, goals, and objectives. Evaluation involved a triangulation approach utilizing multiple modes of inquiry to obtain and relate evaluation information.

Evaluators provided formative information to the project through interim and annual reports³. Evaluation assessed the project in terms of general merit and impact criteria and in terms of specific development and outcome criteria. The Summer Teaching and Learning Institutes provided multiple opportunities to examine methods and content developed by project leaders and staff and to assess participants' satisfaction and training. The following discussion summarizes the results of information gathered about the Institute training and its effects on teachers. Findings were obtained through surveys, questionnaires and focus group discussions and compare the first, second and third teacher cohort reactions to their respective trainings.

In the following discussion, the groups of secondary school teacher participants are referred to as Cohort 1 (n=8) who participated in the first Summer Institute in July 2008; Cohort 2 (n=7) who participated in the second Summer Institute in July 2009 and then again in the third Institute in July 2010; and Cohort 3 (n=8) who participated in the third Summer Institute in July 2010.

A. Survey Questionnaires Analysis and Results

1. Biosystems Technology Summer Institute Questionnaire

The Biosystems Technology Summer Institute Questionnaire was developed for this project and was administered to all three cohorts to assess their views and feelings regarding value of training and their sense of comfort with and readiness to integrate BT curriculum content into agricultural education classes. The seven-item questionnaire was given to Group 1 teachers in printed form at the end of their first Institute training. An identical version was administered online to Groups 2 and 3 during the Institute. The seven items of the questionnaire sought quantitative information by rating scale or categorical responses to stimulus items related to Institute training and other aspects of the BT-ATE project.

Consistently, Cohort 2 and 3 teachers responses most frequently clustered at the highest (most relevant) levels and showed less variability than did Cohort 1 teacher responses. For example, Cohort 1 scored the instructional approach used for the Summer Institutes much lower than Cohorts 2 or 3 (Figure 1). Based on evaluation findings gleaned from discussion, focus groups and journal entries, the contrast between the Group 1 and the later two groups most likely represent the combined effects of alternate recruiting procedures and standards for the later groups and on modifications to Institute content, learning experiences, support materials and requirements instituted by project staff based on their advancing experience in developing teacher readiness to implement the BT curriculum.

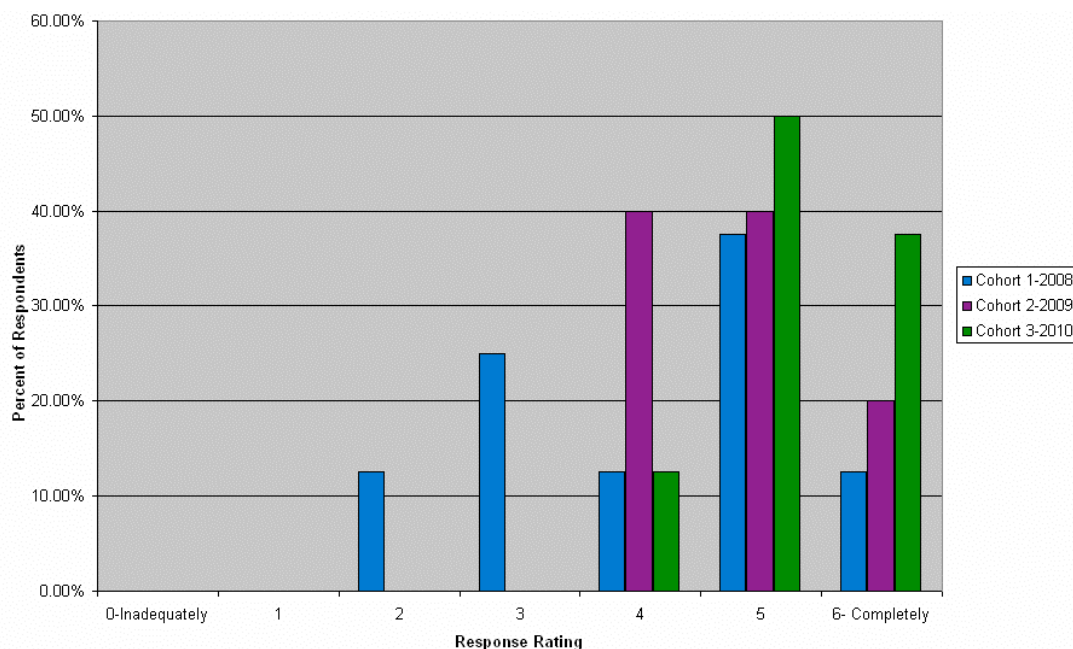


Figure 1. Item 3— Do you feel that the instructional approach used in the Summer Institute has been effective in providing the preparation you need to implement the Biosystems Technology Curriculum in your course(s)? (Cohort 1 n=8, Cohort 2 n=7, Cohort 3 n=8)

These quantitative results are consistent with other sources of data relating to the Institute’s effects in all three years. Most Cohort 1 members expressed in qualitative statements concern about the difficulty of integrating BT material into their courses and also about the challenge of this academic material for their Ag Ed students. No members of the second and third teacher groups mentioned these items in their responses to any evaluation inquiries. There appeared to be a qualitatively significant difference between the first vs. the latter two cohorts in their sense of the achievability of the BT project’s secondary school implementation goals. The latter cohorts consistently appeared more confident and positive about the prospects of successful BT content implementation in their agricultural education classes following Institute training.

2. Teacher Concerns for Biosystems Technology as an Innovation Adoption

As part of the process analysis of the BT-ATE project, external evaluators also examined the ongoing progress of adoption of the program by teachers. Incorporating BT content into agricultural education is an innovation, a new area of educational instruction involving structural, procedural, and value changes from more traditional content areas. Adopting an educational innovation takes time and moves through defined stages starting with awareness and culminating with eventual incorporation and integration into teaching practice. To assess this progress, the Concerns Based Adoption Model[®] and the Stages of Concern Questionnaire[®] were used for evaluation.

The Concerns Based Adoption Model[®] (CBAM) was developed by Procedures for Adopting

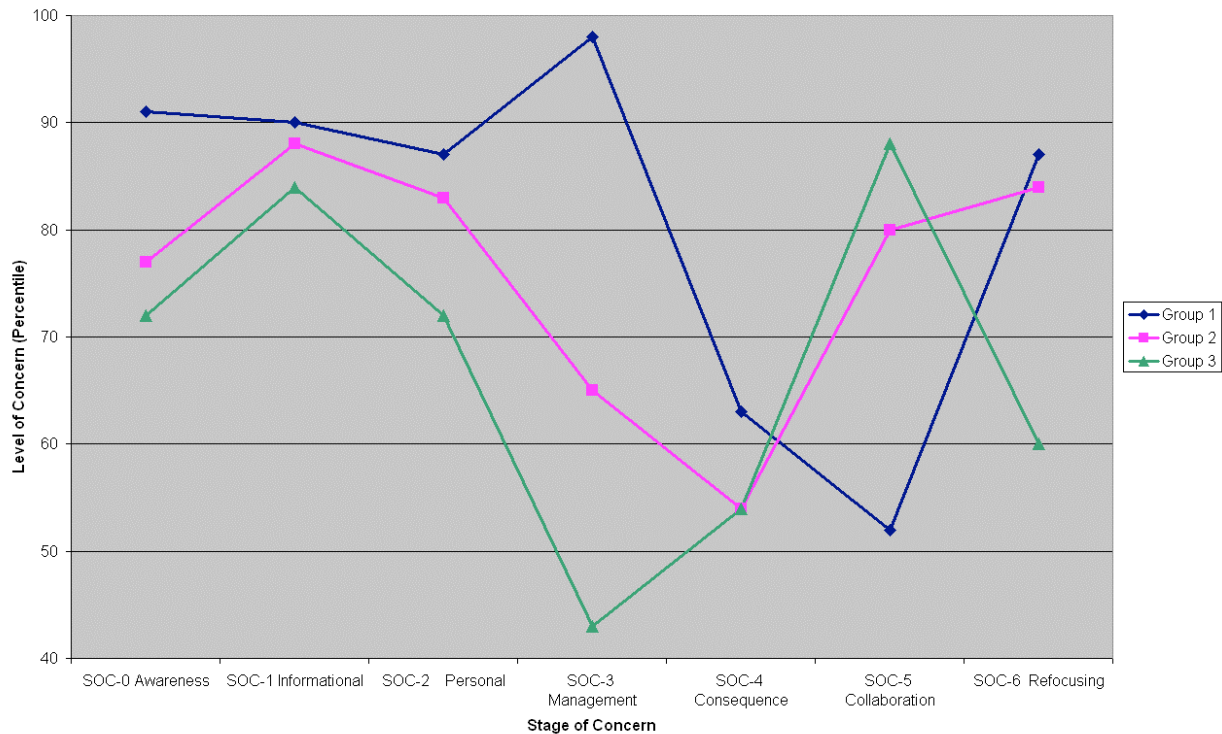


Figure 2. Comparison of Groups 1, 2 and 3 BT-ATE Teachers' Pretest Concerns Profiles

Educational Innovations/CBAM Project R&D Center for Teacher Education at The University of Texas⁴. CBAM proposes a developmental theory in which teachers progress through a sequence of specific concerns during the process of innovation adoption. The Stages of Concern Questionnaire (SoCQ)[®] is a nationally-normed, standardized instrument that assesses level of teacher concern at any of the seven distinct stages of educational innovation. Teachers move from early phases (concern for basic understanding and the consequences for them and on their work), through an intermediate phase (focus on ability to work with or use the innovation), to the most advanced stage (concern about consequences of innovation on student learning/outcomes and for collaborating with others to use the innovation). Each phase must be thoroughly resolved before participants move to the next⁵. SoCQ data can be gathered at any time to determine adopters' concerns and used to guide staff training and to immediately intervene to address predominant concerns.

The Stages of Concern Questionnaire was administered to all three groups of BT teachers after initial Institute participation. The intent was to capture pretest responses at time when each group had comparable Summer Institute preparation for initiating BT activities, but before gaining further experience through practice or through further training or support. In general, all profiles are characteristic of early stage adopters (Figure 2). The earliest stages of concern, Awareness, Informational, and Personal, were high for all groups. This was expected. However, distinct differences were seen among the three group profiles in later stages. These differences are consistent with the other differences found in the evaluations. These group profile differences also relate to the marked difference observed in the actual implementation of BT

material in Ag Ed classes by the first and second cohorts. In the SoCQ results, Cohort I demonstrated a conspicuously higher level of concern (98%) at the Management stage than either Cohort 2 (65%) or Cohort 3 (42%). This stage measures concern for how teachers are to competently apply the innovation in teaching practice.

Cohort I teachers felt less competent to incorporate BT content than did either Cohort 2 or Cohort 3 teachers. This result is consistent with the conclusion from the Biosystems Technology Summer Institute Questionnaire discussed earlier. Following Institute training, Cohort 2 and 3 teachers felt better prepared to manage the implementation of BT curricular content and more confident of their ability to apply the content to teaching than did Cohort 1 teachers at the same point in their development. This impression is further reinforced in qualitative findings based on focus group responses and teacher journal entries, discussed later, and in the distinctly greater success of Cohort 2 teachers as compared to Cohort 1 in implementing relevant material into their classes following their first Institute.

A second interesting comparison is seen at concerns level 5, Collaboration. This relates to the interest of teachers in working collaboratively with others to more effectively incorporate the innovation into teaching practice and to enhance impact on student learning. Cohort 1 teachers were extremely low in their level of concern for collaboration. In contrast, both Cohort 2 and 3 teachers were elevated in collaboration concern. This concerns peak at Collaboration is somewhat surprising for teachers at the early stages of an innovation adoption. However, evaluators observed a high degree of collaboration in practice among the teachers in Groups 2 and 3 during their Institute training. Both groups worked effectively together in laboratory and other hands-on team training activities. Cohort 2 and 3 teachers spontaneously formed themselves into very effective production teams during equipment fabrication activities. A comparable tendency was not noted during the first year of Cohort 1 training.

This finding, if it represents an actuality that can promote adoption and implementation of the BT curriculum, can provide positive support to the project as teachers collaborate and mutually support and reinforce each other's efforts. In interviews and observations, evaluators noted that, during the third project year (the first implementation year for Cohort 2) that Cohort 2 teachers communicated with one another about their project activities, even though the project did not, in that timeframe, offer intentional opportunities for such interaction to occur. In contrast, there was no mutually supportive collaboration observed among Cohort 1 teachers in implementing the BT curriculum or any other processes of the project during their first year post Institute.

Continuation of all Cohort 2 teachers in the BT-ATE project into a second year of Summer Institute training allowed evaluators to acquire posttest SoCQ data for a group that had a year of practice implementing BT content in their courses, and that benefited from the ongoing support of the project leaders during the school year. The results are highly consistent with expectations of advancing adoption of the innovation Biosystems Technology training in secondary school Agricultural Education. The posttest (2010) mean concerns profile for Group 2 represents a more advanced level of adoption for the group than the pretest profile, with earlier stage concerns (Awareness, Informational, Personal, Management) being lower than in the pretest results and later stage concerns (Consequence and Collaboration) somewhat elevated over the pretest results and with predominant concern at the Collaboration stage.

These teachers, in the posttest measurement, continue to demonstrate concern at the Information stage. However, this stage of concern coupled with the increased concern for Consequence (effect of the innovation on student performance) and Collaboration (working with other teachers to extend and increase the impact of the innovation), shows advancement of the process of adoption within this group during their first year of project experience introducing and incorporating BT content into their Ag Ed courses.

Year 3 also allowed evaluators to gather both quantitative and qualitative data about students' experience with the BT material by surveying Cohort 2 teachers. Each teacher's experience differed due to varied space and funds, but the data represent an overall experience.

3. 2010 Quantitative Teacher Survey Data

BT lesson plans were broken into four categories: fabrication activities, lecture/lab demonstrations, laboratory activities and student presentations. The average percentage of time students spent in each activity is as follows: 35% fabrication activities, 25% lecture/lab demonstrations, 30% laboratory activities and 10% student presentations. Active learning predominated BT content, but limited facilities prevented total adoption of the BT curriculum as designed. Yet, teachers were able to modify course content to accommodate their individual institutional limitations.

Cohort 2 teachers also rated student response to new BT content in comparison to previous Ag Ed content on a 5-point Likert scale ranging from much less to much greater. The three areas were: motivation to learn, attentiveness to material and achievement on graded assessments. The results demonstrate positive responses of students to the BT material. All seven Group 2 teachers indicated that both student motivation to learn and attentiveness to BT material was either "Somewhat greater" (n=3) or "Much greater" (n=4) than for more traditional Ag Ed topics.

Six of the seven teachers reported that student achievement on graded assessments for BT material was either "Somewhat greater" (n=3) or "Much greater" (n=3) than for traditional Ag Ed topics, with only one teacher indicating that achievement was generally equal for BT and traditional topics.

Although these findings are based on teacher impressions, they serve as a positive indicator for perceived interest and performance by students in addressing BT material in Ag Ed courses for the first year of successful implementation. These favorable results support the expectation that BT content taught through active "hands-on" learning experiences is interesting and motivating to secondary students, and are corroborated in results of a survey of students seeking to assess their reactions to BT material, as discussed below.

4. 2010 Qualitative Teacher Survey Data

Teachers were also surveyed using open-ended questions regarding their opinions about project related activities, support received and recommendations to other teachers and project managers.

All teachers in Group 2 completed the survey. They were very candid in their responses and were positive overall about their activities in Year 1. All of the teachers were satisfied with the level of support they received from the BT-ATE project staff. All reported getting timely and helpful responses to all email queries and phone calls. One teacher commented that he got anything he needed when he asked, ranging from information to equipment.

Several teachers expressed a desire for information about biofuels in response to a question about additional support for the next year. Teachers discussed student interest in the topic, as well as interest from school administrators. One teacher mentioned a desire for additional funds to work on creating biodiesel. Teachers offered constructive advice to project managers for the coming years of the project. They wanted continued support and communication, and more information about how to prepare students for postsecondary education in BT. Several teachers expressed a desire for more opportunities to meet with one another and with the project managers in order to share ideas and practice using their equipment and teach each other to most effectively convey the BT concepts to students. One teacher said to keep the training going because “we can always become more confident in what we teach.” Other teachers desired a mid-year meeting and more frequent opportunities to communicate with fellow teachers.

Group 2 teachers offered constructive advice about project implementation to Group 3 teachers. They suggested that teachers start early in the school year with BT content to reduce the intimidation factor. They encouraged new teachers to use and adapt BT materials to their own situations and to underscore agricultural standards already in place.

All Group 2 teachers planned to expand on the information gained at the Summer Institute and to increase their students’ exposure to Biosystems Technology and the varied career opportunities it offers.

When both groups were asked what things would they change in future Summer Institutes, two main themes emerged. First, all teachers wanted more information on biofuel/biodiesel production including algal oils. Second, they wanted a mid-year training opportunity. It was proposed to conduct that training during a key agricultural meeting in January for which teacher attendance is mandatory. The BT-ATE project manager was included in this meeting as a guest speaker. Teachers were able to interact with one another and exchange ideas and experiences.

5. Student Survey Data

Year 3 also provided an opportunity to survey students who were exposed to BT content during the school year. An on-line survey was administered to students of Group 2 teachers. Responses from students were more heavily weighted among students who had a higher level of participation in BT classroom and laboratory activities. A total of 33 students responded to a three-item questionnaire that assessed relevance of the material presented and student acceptance of BT content (including constructing solar heaters, algal-based nutraceuticals and renewable fuels) as appropriate for inclusion in Ag Ed courses. Items were scored on a 6-point scale from “Highly Relevant” to “Not Relevant at All”.

Although the patterns of responses vary somewhat across these three response items, the great

predominance of responses (more than 50%) clustered toward the “Highly Relevant” end of the response rating scale. Over 64% of students selected one of the two highest interest ratings and over 80% chose ratings in the upper (more interested) half of the rating scale. This indicates strong interest among the respondent group in further participation in BT learning experiences at the secondary level.

Students were also asked about their interest in post-secondary education in Biosystems Technology and about pursuing related careers in this industry. Responses were scored on a 6-point scale from “Very Interested” to “Not Interested”.

Although student interest in pursuing post-secondary education in Biosystems Technology was less pronounced than for further BT content in secondary, the overall response demonstrated positive interest with over 51% of students selecting one of the two highest interest ratings and over 72% choosing ratings in the upper (more interested) half of the rating scale.

Student interest in a career in Biosystems Technology is a primary outcome desired by the BT project. Although only slightly over 12% of respondents selected “Very Interested, over 48% chose the second highest rating for a total of over 60% in the two highest ratings range and over 75% in the upper (more interested) half of the rating scale.

Over all the three items addressing student interest in Biosystems Technology in further education or career choice, the predominantly positive interest responses demonstrated implementing BT content and learning activities in the respondents’ schools generated interest in the field. These self-reports of student interest in Biosystems Technology are consistent with Group 2 teacher responses discussed earlier indicating the motivating and interest promoting effects of BT learning experiences implemented in project schools in year 3.

B. Focus Group Inquiries—Analyses and Results

At the conclusion of the 2010 Summer Institute training, the evaluation team conducted focus groups with the teacher participants from Cohorts 2 and 3. Focus groups attempt to gather data by asking open-ended questions to elicit discussion in which opinions and thoughts may be shared among group participants that might otherwise be unavailable to evaluators. Focus groups allow researchers to ask probing questions opportunistically to discover and clarify information about topics or themes relevant to the evaluation of programs.

Both teacher groups participated in positive and lively discussions about the week’s activities. Evaluators allowed teachers to talk freely while keeping them on topic and asking probing questions when appropriate.

1. Focus Group Responses and Themes– Group 2 Teachers (7 teachers)

Questions led to conversations and enthusiastic idea-sharing among the teachers and as a result, several themes emerged, as discussed below.

Value and Esteem - All Cohort 2 teachers were enthusiastic about the attention and recognition of their programs by colleagues, school administrators, and parents. The industry grade lab

equipment received as part of the grant generated interest in the program by both students and other teachers at each school. One teacher so impressed his administration that he was able to develop two honors courses for the Aquaculture and Wildlife Program incorporating BT content.

Cutting edge equipment also contributed to the teachers' sense of value. They felt confident about their ability to use it thanks to the training received during the summer. They also believed that this would attract higher achieving students that could validate and elevate the agricultural education program in the eyes of school officials.

Collaboration - Several teachers mentioned that they were beginning to work with their school's science programs using BT content. Many Group 2 teachers shared their equipment with other science teachers and were able to collaborate in teaching across programs. Some teachers reported being invited by non-agriculture teachers to give guest lectures on BT topics to non-Ag Ed classes. One teacher had his students assist in teaching BT topics to non-agriculture students.

Group 2 teachers were not only encouraged about their abilities to collaborate with other programs at their schools, they also expressed a strong desire to collaborate with one another. They enjoyed hearing about each other's BT teaching experiences and project ideas as well as sharing information about teaching BT material. They suggested a meeting of BT teachers at an annual agriculture conference in January (The Young Farmer's Meeting) that they are required to attend. They also thought it would be helpful to invite the BT-ATE project manager to the meeting and suggested holding a panel for all secondary Ag Ed teachers to introduce BT-ATE information and concepts to other agriculture teachers in the state who might be intimidated or not yet familiar with the project.

Resourcefulness - All teachers faced challenges in incorporating BT content. All responded with creative and resourceful solutions that worked in their individual environments. Student ability and academic maturity varies widely in Ag Ed courses. While BT content as taught in the Summer Institute is better suited to higher achieving students, teachers were able to adapt content and learning experiences. All agreed that students were interested in many of the BT concepts and considered environmental awareness important.

The teachers felt that at this time, introducing BT content into already existing Ag Ed courses would be a better approach than trying to create a separate BT pathway. They suggested that a BT career pathway would be more successful later, after more interest has been developed.

Support and Independence - There were no project-related Internet or conference calls in Year 3 due to changes in project personnel. The BT-ATE project manager managed all administrative activities. Overall, teachers felt that they received exceptional support. They reported timely receipt of information and materials when requested and appreciated the availability of the project manager as needed.

When asked about plans for continuing to teach BT materials, teachers indicated they planned to use the equipment more and to expand lessons beyond those covered in the Institute training. Several teachers planned more in-depth lessons on biodiesel/biofuel production. They expressed confidence in their ability to teach and share their own course developments to one another.

The teachers desire to grow in this cutting edge field using their students and their agriculture programs but realize the limitations of available funding for expansion of secondary education offerings. They felt energized by the Institute experiences and the expanded BT content learned in their second Summer Institute. These teachers are willing to seek the expertise to train other Ag Ed teachers in order to continue and expand secondary education in Biosystems Technology.

2. Focus Group Response Items—Group 3 Teachers (8 teachers)

The themes that emerged from these questions were primarily related to motivation for participating in the BT-ATE grant. Major themes were: program enhancement, appeal to students, and opportunity.

Program Enhancement - A variety of reasons were given for teacher participation. Most viewed the BT content as relevant and a good fit to enhance existing agricultural education programs. One teacher saw it as a way to link all the agricultural offerings at the school. Another saw this as a way to protect and perpetuate agricultural programs during tough economic times, and as a way to meet the expectations of his director who favors use of new technologies.

Appeal to Students - Most teachers felt that offering cutting edge material in agricultural science and providing students opportunities to use industry quality laboratory equipment would enhance program interest. Many teachers felt that the curriculum would expand development of critical thinking skills and inspire students academically and career-wise.

Teachers were excited about the new ways they could incorporate math and science skills into the Ag Ed curriculum. They felt that the practical approach used in the BT content would lessen math anxiety and result in higher levels of self-confidence regarding their academic abilities. They felt the hands-on lab format stimulates student interest and that the approach allows teachers to move beyond cookie cutter lesson plans and cookbook chemistry.

Opportunity - All teachers saw the BT-ATE project as a way to move beyond the concepts of food and fiber and into a rapidly expanding and increasing important field. The BT approach offers a way to examine familiar concepts in different and practical ways. Teachers felt that this project would enable them to create more “ah ha” moments for students in the classroom and broaden their horizons.

Challenges - Group 3 teachers found the technological aspects of the Institute very challenging. Using software to create a poster or to tabulate data provoked anxiety, and more than one teacher was concerned about completing the poster on time. Others stated that their routines at school allowed little time for computer use since they were outside most of the day.

Some teachers expressed concern that they might not know how to use all of the equipment when they returned to their classrooms. They suggested using some of the down time during the Institute to review construction piece by piece.

Teacher Influence - Many of the Group 3 teachers knew Group 2 teachers and were influenced

by their familiarity with them from professional development activities and agricultural meetings. Word of mouth played a large role with Group 3 teachers. One Group 3 teacher heard about the project when enrolled in a summer course with a Group 2 teacher. A colleague at a neighboring school influenced another after hearing about project equipment and resulting student activities. Another attended the Annual Agricultural conference and heard the BT-ATE project manager speak. He asked to join because he thought it would excite his students.

Collaboration - Group 3 teachers also expressed a desire for more time with one another to discuss ideas, describe their individual programs, and share stories that would allow for program growth for everyone's school. These teachers also mentioned the annual Young Farmer's Meeting which takes place in January and thought it would be a great time to gather and invite the BT-ATE project manager as well to discuss their project developments and activities.

C. Evaluation conclusions

Findings from various modes of evaluation confirm that the BT project was effectively conducted according to the original plan with some reasonable departures required to address obstacles as they were encountered. A supplemental one-year grant from NSF allowed PIs continue to extend the project's goal and objectives.

The BT-ATE Project's goals, objectives, and intentions are ambitious, attempting to simultaneously develop and introduce a challenging curriculum innovation into three levels of education in three years. The efforts of project leaders have been diligent and determined. The extent to which the project has not fully realized its aims is entirely due to real-world circumstances of implementation and do not represent either failure of effort by project leaders and staff or lack of good intent by participants.

The challenges to completion of such an undertaking are great. Unpredictable organizational changes and inherent resistance to adoption of innovations in public education complicated efforts. However, because of the resolute, flexible, and creative work of project leaders and staff, there was steady progress, despite all obstacles, toward realizing project goals and objectives. Many lessons were learned from the experience and those lessons have been applied to revise methods used to bring the project to a successful conclusion. Some of those lessons inform several recommendations for consideration as project investigators consider how to continue their initiatives to fully realize the aims of the BT-ATE project in the future.

D. Evaluation Recommendations

Training and mentoring of teachers is essential, as is sharing equipment to reduce costs. Secondary teachers want opportunities to communicate with each other. This is key to educational innovation adoption. Taking advantage of opportunities for connection among the teachers at periodic conferences that they routinely attend is a preferred format. Conduct online meetings for secondary teachers to discuss progress and implementation issues.

Provide adequate project staffing and support. To the extent that resources allow, ensure that research assistants are available to support project operations. The employment of support staff

is crucial for PIs to meet the requirements of such a complex, multi-faceted project.

Projects intended to effect innovation in public schools take a considerable amount of time for gradual progress to occur. Many intrinsic aspects of public school impede quick adoption of innovations. If possible, seek funding for at least five years for this kind of effort.

V. Conclusions

An innovative curriculum in Biosystems Technology (BT) was developed at the secondary, technical college and university levels, through collaboration of Biosystems Engineering, Agricultural Education and Biological Sciences investigators. The BT curriculum focuses on applications in biological systems that transition student learning and depth of understanding from one level to the next. BT courses were implemented at both the university and secondary levels. Evaluation results indicate the program was successful in educating students with increased STEM knowledge, with an emphasis on engineering content, to prepare them for the technical workforce in the growing biofuels and bioprocessing industries.

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