A Delphi Study to Identify Recommended Biotechnology Competencies for First-Year/Initially Certified Technology Education Teachers

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Background

The world is a dynamic environment driven by technology that challenges each individual in a unique way. No longer is the ability to read and write sufficient because technological change affects nearly every aspect of one's life from "enabling citizens to perform routine tasks to requiring that they are able to make responsible, informed decisions that affect individuals, our society, and the environment" (International Technology Education Association [ITEA], 2003, p. 1). To "combat uncertainties about biotechnology and technology transfer firsthand knowledge of these technologies must become part of the education of each child" (De Miranda, 2004, p. 78). As a result of these technological developments, a challenge to all classroom teachers is to meet the needs of a diverse K-12 learning population. Technology education (TE) teachers in particular have been challenged to prepare students for life in a society dominated and driven by technology. To strengthen and ensure the future vitality of the United States' human resources and biotechnological enterprises, educators and professionals in the field of biotechnology must work together to develop competencies that meet students' needs (California State University Program for Education and Research in Biotechnology, 2001). To meet these challenges, technology stakeholders have collaborated to develop a variety of technology literacy standards and teaching methods. In particular, the ITEA published *Standards for Technological Literacy: Content for the Study of Technology* (*STL*) (ITEA, 2000). This document established a definition of technology, technological literacy, and the content standards needed for K-12 classrooms.

The *STL* (ITEA, 2000) presented a "vision of what students should know and be able to do in order to be technologically literate" (p. vii) through 20 content standards for grades K-12. The ITEA publication also established content benchmarks for the core areas of technology. One of the core

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technology content areas addressed by the *STL* is biotechnology. The *STL* Standard 15 states that "students will develop an understanding of and be able to select and use agricultural and related biotechnologies" (ITEA, 2000, p. 149). This standard proposed that secondary (grades 9-12) students should be able to study the effects of waste and pollutants, discuss the need for government regulations, and conduct research and present their findings on the positive and negative effects of a process, product, or system in the field of biotechnology.

The *STL* Standard 15 (ITEA, 2000) also established benchmarks (written statements that describe the specific developmental components by various grade levels that students should know or be able to do in order to achieve a standard) for biotechnology. The benchmarks progressively build on one another throughout the elementary, middle, and high school levels. The four benchmarks addressed by this research state in order to select, use, and understand agricultural and related biotechnologies; students in grades 9-12 should learn that:

K. Agriculture includes a combination of businesses that use a wide array of products and systems to produce, process, and distribute food, fiber, fuel, chemical, and other useful products.
L. Biotechnology has applications in such areas as agriculture, pharmaceuticals, food and beverages, medicine, energy, the environment, and genetic engineering.
M. Conservation is the process of controlling soil erosion, reducing sediment in waterways, conserving water, and improving water quality.
N. The engineering design and management of agricultural systems require knowledge of artificial ecosystems and the effects of technological development on flora and fauna (p. 155-156).

Dunham, Wells, and White (2002) asserted that "Few fields in the modern world have advances as rapid as those that have taken place in biotechnology" (p. 65). Yet, the *STL* (2000) did not identify an organized and validated list of biotechnology competencies for teacher education programs (nor was it intended to do so). Russell (2003) believed that few TE teachers have been instructed in biotechnology, and instructional strategies being used to teach biotechnology may be inadequate. Rogers (1996) also reported that only 3.5% of the institutions surveyed included biotechnology in their industrial/technology teacher education programs. Russell (2003) further stated "if current students were tested on all of the ITEA standards; it is likely that biotechnology scores would be lower than in some more traditional areas within technology education" (p. 30).

The Council on Technology Teacher Education (CTTE) Undergraduate Studies Committee also recognized there was a need to identify and establish technical competencies for technology teacher education programs. At the 2003 ITEA conference, the CTTE identified their goals for 2003-2004. One goal was to develop teacher education competencies for all core technology content areas. Recognizing the magnitude of this task, the Undergraduate Studies Committee agreed to begin with only one content area: biotechnology (grades 9-12) (C. P. Merrill, personal communication, March, 13, 2003). As a result, this research was conducted as a CTTE charge to identify, develop, and validate a list of critical biotechnology competencies. However, this study did not attempt to address how technology teacher education programs determine curriculum content or where biotechnology would fit into teacher education curricula. Rather, the findings of this research were to act as an initial starting point for the development and validation of biotechnology competencies.

Purpose of the Study

The problem driving this study was the lack of recognized and validated biotechnology competencies to be included in technology teacher education programs. Therefore, the purpose of this study was to identify, develop, and validate the critical biotechnology competencies that should be acquired by first-year/initially certified secondary TE teachers to enable them to include selected biotechnology content in their classrooms (grades 9-12) in alignment with ITEA Standard 15 (ITEA, 2000).

Research Methods

Research Design

This research incorporated a Web-based modified Delphi technique based on an initial competency list created from existing literature. The Delphi was used to consult a body of experts, gather information, and formulate a group consensus while limiting the complications and disadvantages of a face-to-face group interaction (Isaac & Michael, 1981). In addition, the electronic Delphi was used to reduce the potential for dominance by a panel member or distortions (i.e., "group-think") arising from decisions based on panel member feedback (Clayton, 1997).

The primary purpose of choosing the Delphi technique was to obtain a consensus of opinion from experts knowledgeable in biotechnology. The Delphi exhibited three distinct characteristics useful for this study: anonymity, interaction with controlled feedback, and statistical group response. Through the Delphi, participant anonymity was secured allowing individuals to change their opinion on the subject matter while preventing them from being persuaded or inhibited (Clayton, 1997). Consistent with Wells (1994), an abstract explaining the context of the study was used as an informative measure. Using an abstract is an adaptation of the traditional Delphi technique; however, the characteristics (e.g., anonymity, controlled feedback, and statistical group response) consistent with committee problem-solving activities were maintained.

Achieving group consensus through the Delphi process is a function of the validity and quality of the initial competency selection process through the literature review (Custer, Scarcella, & Stewart, 1999). The literature review revealed extensive similarities in the core content organizers for biotechnology. Therefore, the advisory committee determined two rounds of feedback were sufficient for this study. Round One allowed the panel to recommend changes, suggest deletions, and/or make additions to a researcher-developed list of biotechnology competencies based on the literature review. Round Two sought panel member consensus on the biotechnology competencies proposed, revised, and deleted by Round One. To maintain bias control, the Web-based instrument and resulting data were maintained by an independent researcher who had no direct affiliation with the study. Upon completion of each round, the researcher disseminated only aggregate data for evaluation by the advisory committee.

Delphi Panel Selection

The selected Delphi participants who served on the panel represented a nationwide selection of “cross-disciplined” biotechnology stakeholders (biotechnology industry, organizations, and government personnel, technology teacher education faculty, secondary education technology teachers, and a graduate student). Potential panel members were identified from recommendations by biotechnology professionals and educators, input from the ITEA/CTTE Undergraduate Studies Committee, a call for participation and recommendations from ITEA's online list-serve (Idea Garden), and recommendations by the research advisory committee. Initial consideration for those nominated as a Delphi panel member was based on their knowledge of biotechnology content, ability to represent feasible yet diverse viewpoints, ability to communicate feedback to the research panel, and/or a demonstration of expertise in biotechnology that established each participant as knowledgeable (Finch & Crunkilton, 1999; Walker & Echternacht, 1992).

The selection process also focused on individuals actively engaged in the field of biotechnology. Consistent with (Sharp et al., 2003), the Delphi panel members were also considered based on the following criteria: (1) a demonstrated particular interest in the field of biotechnology by either service or research; (2) possessing previous experience in biotechnology in general practice; and/or (3) being recognized as biotechnology experts by their colleagues. Individuals who did not meet these criteria were excluded from participation.

Potential panel members were contacted via e-mail requesting voluntary participation in the study. The respondents who replied positively received a second e-mail that presented a detailed study overview, a letter of informed consent for their participation, and their Federal human subjects' rights as panel members. Consistent with Clayton's (1997) recommended Delphi panel size, 16 members (11 men and 5 women) were selected to participate in Round One of the study. The panel included two government employees associated with the field of biotechnology, two biotechnology organization/industry professionals, two medical professionals, four secondary TE teachers who actively included biotechnology content in their classrooms, four technology teacher education faculty, one graduate student whose program of study emphasized biotechnology content, and one consultant specializing in biotechnology and genomics.

Instrumentation

To maintain anonymity, panel members were provided a unique identification number and link to the instrument. Panel members were also provided a cover letter that included a Delphi introduction outlining the features of the instrument, an operational definition of biotechnology, a link to ITEA Standard 15 (ITEA, 2000), and a description of the scope of the research. For the purpose of this study, biotechnology was operationally defined as any technique that uses living organisms, or pairs of organisms, to make or modify products (e.g., genetic engineering, tissue culturing), improve plants or animals (e.g., transgenics, therapeutic human cloning, genetically modified foods, etc.), or to develop microorganisms for specific uses (e.g., genetic therapeutics, microbial structures and applications, agrichemicals) (ITEA, 2000).

The Delphi for Round One feedback was sought on a list of 31 literature-based biotechnology competencies and seven content organizers. Consistent with Custer, Scarcella, and Stewart (1999), the researcher-developed competency list was used to provoke discussion and serve as an initial starting point for the panel. The content organizers included Biotechnology Fundamentals, Bioethics, Environment, Genetic Engineering, Agriculture, Medicine, and Skills. The Delphi instrument provided panel members with three feedback options (*accept as is; delete, not needed; and change to*) for each item (see Figure 1).

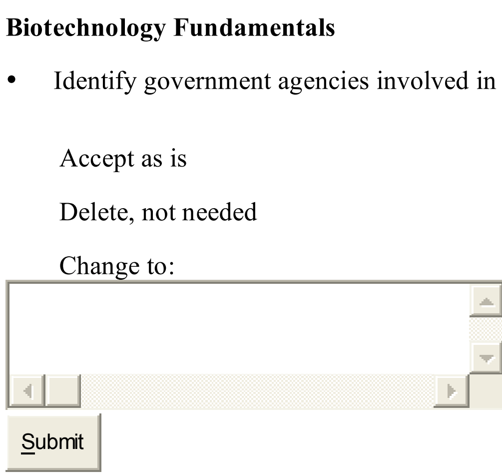

Figure 1. Competency feedback page.

To enter feedback, the panel members selected the option that best represented their recommendations. Once an option was selected and/or text added, the submit button was used to send the information to the database. When the "change to" option was selected, a text box (unlimited characters) was provided for the panel members' feedback. The Delphi instrument allowed panel members to stop and restart as needed. If a panel member wanted to add a competency or content organizer, it could be entered into a designated text box. Panel members indicated completion by selecting the appropriate box which sent their final information to the database.

Round One of the Delphi instrument was accessible to panel members for a period of two weeks (October 20, 2003, through November 3, 2003). Following Round One, the Delphi Round Two consensus recommendations were posted online for ten days (November 14, 2003, through November 24, 2003) for panel member feedback. As stated in the letter of agreement to participate, panel members were not required to respond to competencies in areas in which they were not knowledgeable or comfortable. Those indicating completion without reviewing all 38 line items were not required to provide any justification or rationale for doing so, or provide feedback for Round Two.

During Round One, consensus was achieved all 38 line items with an overall acceptance rate of 80.4%, ranging from 68.8% to 93.8%. However, panel member feedback identified 46 recommended changes and/or additions to the Delphi competency list. Fifty-six percent (9 of 16) of the panel members responded to all 38 line items presented for Round One (see Table 1).

Table 1. *Round One panel member participation rates.*

Panel Member No.	No. of Items Completed	Percent	Bar Graph
1	38	100.0	
3	38	100.0	
4	38	100.0	
5	38	100.0	
6:	38	100.0	
11	38	100.0	
13	38	100.0	
15	38	100.0	
16	38	100.0	
10	36	94.7	
2	34	89.5	
7	29	76.3	
14	26	68.4	
9	25	65.8	
8	21	55.3	
12	13	34.2	

Based on the Delphi panel feedback, an amended list of eight content organizers and 44 competencies was posted online as the Delphi Round Two. The amended list included the following revisions from Round One: five changes and two additions were made to the Biotechnology Fundamentals content area; four changes and two additions were made to the Bioethics content area; two changes and one addition were made to the Environment content area; two changes and one addition were made to the Genetic Engineering content area; two changes and two additions were made to the Agriculture content area; four changes were made to the Medicine content area; one content area (Industry) and three new competencies were added, and the Skills content area was changed to Bioinformatics with three additional competencies added.

Twelve panel members provided feedback for the Delphi during Round Two, which concluded with all 52 line items achieving consensus with an overall group acceptance rate of 89.3%. This group acceptance rate constituted an increase of 8.9% above that posted for Round One. During the feedback period, 11 of the 12 panel members who participated indicated they had completed Round One. One of the 12 panel members reviewed only 22 of the possible 52 line items (42.3%) and did not indicate completion. The 11 panel member response rates for those who indicated completion during Round Two averaged 94.75%. Two of the panel members who did indicate completion also chose to exercise their option to not respond to all 52 line items. The response rates for these two panel members were 86.5% and 55.8% (see Table 2).

Table 2. *Round Two panel member participation rates.*

Panel Member No.	No. of items completed	Percent	Bar Graph
1	38	100.0	
2	38	100.0	
3	38	100.0	
4	38	100.0	
5	38	100.0	
7	38	100.0	
8	38	100.0	
10	38	100.0	
11	38	100.0	
6	45	86.5	
9	29	55.8	

Seven changes (1.1%), no deletions, and six potential additions were recommended by the panel during Round Two. Six of the recommended changes were editorial and grammatical changes, which were accepted for clarification purposes. Five recommended additions were determined to exceed the scope of this study, were deemed to be instructional strategies rather than program competencies, or were already represented within the content organizers and/or existing competencies. The one competency added to the final list was in the Bioinformatics content area. A recommendation to drop the definition of Bioinformatics and change it into a competency was accepted and included on the final list..

Results

This study produced the following final list of eight biotechnology content organizers and 45 biotechnology competencies.

Biotechnology Fundamentals

1. Describe biotechnology and its global impact on society, culture, and the environment.
2. Identify and discuss international organizations and government agencies involved in biotechnology.
3. Compare and contrast the limitations and advantages of biotechnology.
4. Discuss biotechnology research, companies, careers, and career preparation.
5. Recognize and practice biotechnological safety procedures.
6. Identify and demonstrate biotechnology tools and equipment.
7. Define biotechnology and discuss its applications and its relationship with other technologies (i.e., medical, agricultural, and environmental).
8. Discuss the history of biotechnology and its impact on the future.

Bioethics

1. Identify the principles of ethics.
2. Discuss the bioethical issues arising from medical developments and processes (i.e., gene therapy and the patenting of life).
3. Discuss the bioethical issues arising from environmental developments and processes (i.e., inadvertent cross polination and bioremediation).
4. Discuss the bioethical issues arising from agricultural developments and processes (i.e., trangenics and genetically modified foods).
5. Describe ethical methods of addressing biotechnology issues.
6. Compare and contrast bioethics perceptions in the United States with perceptions in other countries.

Environment

1. Summarize how biotechnology impacts the environment.
2. Compare and contrast bioremediation methods with traditional remediation methods.
3. Discuss the environmental impact of biorestoration techniques.
4. Identify the biotechnologies suitable for waste disposal and treatment.

5. Compare and contrast physical and biological containment systems and how each protects the environment.

Genetic Engineering

1. Identify basic cell structures and research techniques.
2. Describe the process of genetic modification.
3. Illustrate a model of the genetic code.
4. Explain genetically modified foods, animals, and therapeutic human cloning.
5. Identify applications of genetic engineering, new and emerging, in the fields of agriculture and medicine.
6. Summarize the global impact of genome projects on civilization.

Agriculture

1. Appreciate the biosafety aspects of food and agricultural biotechnology.
2. Compare and contrast the potential benefits and risks of genetically modified foods versus traditional food production methods.
3. Identify emerging applications of biotechnology in plants and animals.
4. Identify how agricultural biotechnology reduces dependence on insecticides and reduces environmental and human exposures.
5. Summarize the impact biotechnology has upon agriculture.
6. Describe current social and political issues arising from bio-agriculture products and their effect upon international trade (e.g., genetically modified foods in Europe).

Medicine

1. Discuss the social, cultural, and political implications biotechnology has on medicine.
2. Identify genetic therapeutics and discuss how they have impacted health care.
3. Explain how immunology has impacted disease prevention.
4. Summarize how molecular medicine and health care technologies have impacted humankind.

Industry

1. Identify the emerging applications of biotechnology in industrial environments (i.e., new plastics and enzymes).
2. Compare and contrast the advantages and disadvantages of industrial biotechnology applications have upon humankind and environmental safety.
3. Describe the new industrial markets and business opportunities created through biotechnological products and processes.

Bioinformatics

1. Present an overview of bioinformatics (informational technology as applied to the life sciences, especially the technology used for the collection, storage, and retrieval of genomic and proteomic data).
2. Present related fields to bioinformatics (i.e., computational biology, cheminformatics, and medical informatics, etc.).
3. Identify the major tools and discuss the challenges facing bioinformaticians today.
4. Demonstrate exercises in developing and transferring data.
5. Facilitate open-ended design based problem solving in biotechnology.
6. Integrate the usage of computerized materials and the reading and understanding of technical materials.
7. Design basic laboratory exercises to demonstrate biotechnology (e.g., use of genetic markers and herbicide tolerances).

Discussion

The ITEA recognized the importance of including biotechnology content in secondary education classrooms by developing Standard 15 (ITEA, 2000) that established specific benchmarks for elementary, middle, and high school students. The CTTE Undergraduate Studies Committee also recognized the importance of including biotechnology with its 2003-2004 charge to identify, develop, and validate the critical biotechnology competencies that future secondary technology education teachers should possess to facilitate student learning under the ITEA *STL* benchmarks. However, standalone competencies do not establish how much biotechnology content is appropriate for student instruction, how biotechnology should be included in secondary education classrooms, or who teaches biotechnology content to students. Through the execution of this study, the identification, development, and validation of an initial set of critical biotechnology competencies for technology teacher education programs was accomplished. Yet, the steps needed to obtain further feedback and acceptance by those with a vested interest in the future of biotechnology education is unknown.

While ITEA Standard 15 and the charge by the CTTE Undergraduate Studies Committee served as the catalysts for developing the biotechnology competencies that were the focus of this research, the competencies identified may exceed the breadth and depth of the Standard. Specifically, the content organizers Industry and Bioinformatics, with their related competencies, may not be included in the *STL.* Therefore, there is a need for continued study and debate by all biotechnology education stakeholders.

Biotechnology Content and Teacher Education Programs

Technology teacher education programs are structured by a core of required and elective courses based on a total number of cumulative hours required for a bachelor’s degree. Currently, most technology teacher education degree programs being offered do not include biotechnology content (Rogers, 1996; Russell, 2003). Adding additional hours to existing programs will require content to be either eliminated, or hours to be added to programs of study.

Determining how to integrate biotechnology into existing teacher education programs will become more prominent in the future (Dunham, Wells, & White, 2002). However, including biotechnology content within the structure of current technology teacher education programs, compounded by the procedures required to change program content or add additional hours to degree requirements, may be difficult to accomplish. The appropriateness and feasibility of including biotechnology content in technology teacher education programs, either as standalone TE courses or through creating partnerships with biology or traditional science programs, should be explored.

Biotechnology stakeholders may also argue that teaching biotechnology content in secondary classrooms should remain in traditional science and biology programs rather than TE classrooms. In contrast to this opinion, the development of ITEA's Standard 15 (ITEA, 2000) supports the position that technological literacy includes biotechnology content (or any other core area) that should be included in secondary education regardless of who delivers it. Including biotechnology content requires competent and literate teachers who possess the critical biotechnology competencies needed to facilitate student learning. As a result, the future of biotechnology in the secondary educational system is contingent upon the preparedness of *all* teachers who are charged to deliver biotechnology content in their classrooms. This may create problems for technology teachers who are currently being ill-prepared by many technology teacher education programs (Russell, 2003). To facilitate teaching biotechnology in secondary education, TE teachers need to be adequately prepared to deliver selected biotechnology content.

Rogers (1996) and Russell (2003) also report that many institutions offering TE teacher education programs have chosen to completely ignore biotechnology content. It may be unlikely that those ignoring biotechnology will accept or recognize the competencies identified and validated by this study as the definitive set. Furthermore, it may also be unlikely those TE teacher education programs will move towards including biotechnology based on this study's results. Regardless of whom the task of including biotechnology in secondary education classrooms falls upon, the critical biotechnology competencies identified and validated by this research may become instrumental in teacher education programs that prepare future secondary educators including, traditional science teachers, TE teachers, or others.

The opinion that biotechnology content should be taught across multiple disciplines, which includes TE, supports ITEA Standard 15 and this study's purpose to identify, develop, and arrive at a consensus on the critical biotechnology competencies needed by TE teachers. By achieving a consensus, a critical list of biotechnology competencies was established that should be included in teacher education programs. Further development of these competencies may lead to more inclusion and development of a curriculum to prepare teachers to include biotechnology in secondary classrooms.

Conclusions

The Web-based modified Delphi technique applied to this research was an effective method of obtaining data from a diverse group of panel members widely separated by distance and may be useful in future studies establishing content in other TE core areas. The panelists reached consensus on 45 critical biotechnology competencies under eight content organizers that they felt should be acquired by secondary TE teachers to prepare them to include selected biotechnology content in their classrooms. They include Biotechnology Fundamentals, Bioethics, Environment, Bioengineering, Agriculture, Medicine, Industry, and Bioinformatics. The initial list of biotechnology competencies identified through the extensive literature review was consistent with the validated list produced by the Delphi panelists as representing those that should be possessed by first-year/initially certified secondary TE teachers. The literature reviewed and data produced by this study substantiated the need to include biotechnology in technology teacher education programs to facilitate student learning of the benchmarks for grades 9-12 identified by ITEA Standard 15.

Recommendations

1. Revisions should be made to preservice technology teacher education programs so that graduates are competent to deliver the 45 critical biotechnology competencies established and validated by this research. By inference, teacher inservice programs may also need to be modified.
2. Further research into the current state of preparedness of secondary TE teachers to deliver the 45 competencies identified and validated by this research should be conducted.
3. Due to the blend of science and technology encompassed in the biotechnology competencies identified by the cross-disciplined Delphi panel, it is recommended that traditional "isolationist" models of instruction be revised at both the secondary and university teacher education levels in favor of a collaborative teaching strategy.
4. The competencies identified by this research may represent a potential starting point for including biotechnology content in teacher education programs on an international level. These competencies should continue to be further refined through discussion and debate.
5. Further research should be conducted regarding the feasibility and extent of biotechnology content that can be included within technology teacher education programs.
6. A biotechnology curriculum guide based on the identified competencies should be developed to facilitate the inclusion of biotechnology into technology teacher education programs.
7. This study should be replicated using a ranking method focused on developing quantitative data to further validate the critical biotechnology competencies identified.

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