Establishing a Taxonometric Structure for the Study of Biotechnology in Secondary School Technology Education

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Traditional biotechnology was a part of human history long before the realization of its mechanics. Historically it has been an integral part of the human social structure, continually changing the shape and visage of our society. The change has been progressive, with a pervasiveness that insures its lasting inclusion in every aspect of our daily existence. The advent of a *modern* biotechnology revolution was sparked less than twenty years ago, and was clearly underway at the onset of this decade. Current developments in biotechnology are proceeding at accelerated rates similar to those seen in the microelectronics boom of the 1970s.

Modern biotechnology is a technology with enormous potential that will involve extensive research and development throughout the 1990s. During the next few decades advances in biotechnology will require individuals associated with the biotechnology industries to receive specific education and training, and in addition, will result in the need for increased public awareness of its potential benefits and negative consequences. New scientific knowledge, and the appropriate technologies accompanying it, cannot take root and be purposefully controlled in the absence of an informed public. Those in education, both in this country and abroad, have begun to realize the enormous potential biotechnology will have for influencing our future lives, and are beginning to address the need for its inclusion in secondary curricula (Royal Society, 1982; Gayford, 1987; Project 2061 Panel Report, 1989; Wise, Buonopane, and Blackman, 1990). However, these initial attempts are taking place largely in the hard sciences (i.e. chemistry and biology) and engineering. There is a danger in directing such instruction at a narrow segment of the student population. That which serves the specialists does not necessarily fit the needs of the majority. In particular for biotechnology, a broad scientific and technological education is required that fits the overall goals of general education.

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The increased attention currently being given to biotechnological advances has brought with it an increased understanding of the technical aspects inherent in the various biotechnical processes. In light of this, contemporary professionals in technology education are recognizing that biotechnology has a natural place within their general education curricula, and must be made part of the instructional program (Wittich, 1990). Recently strong support for this move was presented in *A Conceptual Framework for Technology Education* (Savage and Sterry, 1991). The foundation of this new document incorporates many of the concepts used in the *Jackson's Mill Industrial Arts Curriculum Theory* document (Snyder and Hales, 1981), and suggests, as did the first document, a model for the development of a technology education course of study. The model specifically points to the need for development and inclusion of biotechnology in technology education instruction (Savage and Sterry, 1991), and ultimately recommends it as a fourth content organizer, along with transportation, production, and communication.

The technology education profession has come to recognize the importance of including biotechnology within its discipline, and is poised to put forth the efforts required to do so. They are in line with those other professions in education involved with developing curricula for biotechnology. Requisite of this however, will be the development of a structure from which biotechnology content is derived and made deliverable within an instructional setting. Such development inherently precludes serious consideration of new content within a discipline. However, fundamental to the development of any biotechnology curricula or instructional program is agreement on a content structure and those seminal elements that comprise it. Lacking from those professions involved with biotechnology instruction is the research-based determination of a structure from which the content is derived.

Purpose

This research was performed in response to the absence of an agreed upon curriculum structure for incorporating instruction in biotechnology at the secondary level. The purpose of this study was to develop a conceptual model of the first two hierarchical levels of a biotechnology taxonometric structure. Specifically, such a taxonomy, derived through expert consensus, would allow for future development of secondary biotechnology curriculum, applicable both within a technology education program or biological sciences program. To this end the following research question was addressed in this study:

1. To what degree can consensus be reached, through a panel of experts, on the primary components of a biotechnology taxonometric structure for the secondary school level?

Methodology

For this study, and eventual use at the secondary education level, the term *biotechnology*, taking into account both traditional and modern techniques, is defined as:

> ...any technique that uses living organisms (or parts of organisms) to make or modify products, to improve plants or animals, or to develop micro-organisms for specific uses (Office of Technology Assessment, 1988, 1991; Federal Coordinating Council for Science, Engineering, and Technology, 1992).

The research method used in this study was the Delphi technique. The fundamental purpose of this technique is to obtain a consensus of opinions from a panel of experts, and was seen as an appropriate initial procedure for determining instructional content. Four sources were identified from which prospective panel members would be chosen. The sources identified were (a) major biotechnology companies; (b) educational organizations associated with science and technology; (c) government agencies associated with science and technology; and (d) universities with major biotechnology departments. From each of the four sources a pool of individuals was sought, from which a total of twenty would be randomly selected. The initial size of the entire pool of potential participants was 151 individuals, with selection based on a pre-determined set of criteria for identifying experts. Five individuals from within each of the four sources were selected at random, culminating in a total of 20 potential panel members. The resultant 20 member panel of biotechnology experts was evenly split between 10 males and 10 females. This split was a purely random occurrence.

This study used three instruments that are identifiable as Delphi I, Delphi II and Delphi III. A three round Delphi sequence is considered ideal, as it has been shown to take into account virtually all (99%) of the changes in respondent opinions by the end of the third round (Martino, 1975; Weatherman and Swenson, 1974).

The instrument used for Delphi I was developed as an unstructured, characteristic-retaining variation of the model Delphi approach. Initiating the study with a delimiting context is a variation on the classic Delphi method, supported through research conducted by Martino (1975). A modification of this type calls for an abstract to preface the first round instrument, providing the panelists with the context of the study as an informative measure. It is an adaptation however, in which the characteristics originally intended to eliminate disadvantages concurrent with committee problem-solving activities (i.e. anonymity, iteration with controlled feedback, and statistical group response), are maintained. The panel members used in this study all had expertise in, or related to, the field of biotechnology. However, considering the institutional diversity of these individuals, the potential existed for their viewpoints to differ drastically. Hence there was a need for the modification in order to present a common information base with round one, that provided the members with an initial context reference point from which to view the issue.

Consequently, a brief abstract clarifying the context within which to view biotechnology was included with the round one questionnaire packet. The abstract specified (a) the philosophical and instructional basis for technology education, (b) the targeted level of instruction, (c) the purpose of that instruction, and (d) the environment in which it would take place.

With a common contextual base established, the Delphi I questionnaire could then be presented in an unstructured, open-ended response format. Experts were requested to designate knowledge areas representing the *major* areas of biotechnology endeavor, and to then denote the subdivisions each area could be broken into as the next level in a structural hierarchy. In addition they were asked to give a brief rationale for their structure.

The hierarchies received from Delphi I were reviewed by a local committee composed of the technology education researcher and two local biotechnology experts, to identify unique biotechnology knowledge areas. Uniqueness was based on the following set of guiding principles, adapted from taxonometric studies in the technology education field (DeVore, 1966), to serve as selection criteria for a biotechnology taxonomy: (a) areas are mutually exclusive; (b) the word or phrase chosen delimits the area; (c) each area has a distinct universal concept that is inherent to the biotechnology knowledge base; (d) there is an internal relationship existing between areas; (e) the areas are universal, being international in scope and not bound by geographic or social boundaries.

Using this set of principles, biotechnology knowledge areas were derived by the local committee through an analysis of the titles and their associated subdivisions obtained from the returned Delphi I responses. Determination of these unique areas made possible the alignment of suggested subdivisions under the appropriate knowledge areas. The amalgamated structure became the basis for the Delphi II and III instruments.

In the second Delphi round experts were presented with the biotechnology knowledge areas that emerged from the first round responses. For each major area experts were asked to make judgments on the subdivisions listed below each knowledge area by rating them according to their degree of agreement or disagreement for inclusion in that particular biotechnology knowledge area. An eleven point scale ranging from 1 (not important) to 11 (critical) was used to rate the subdivisions. The higher the rating, the more the panel member indicated the subdivision was critical for thorough instruction in a given knowledge area. Space was also provided beneath each subdivision to allow respondents to give comment concerning their chosen rating score.

The returned scales were first examined for accuracy in following instructions. Scores assigned by the panelists were used to determine the 25th, 50th and 75th percentiles, and general descriptive statistics for each subdivision within all knowledge areas. Modal ratings for each item, and the respondent's rating position with regards to the mode, were incorporated into the third instrument mailed in the Delphi III packets.

In round three experts were provided with the results of the second round and asked to reexamine the scores on the scale report, with special consideration given to their position on a given item. They then had the option of adjusting their judgments or leaving them unchanged. Comments obtained from the Delphi II concerning specific subdivisions were included with the Delphi III instrument as a means of passive persuasion for individual panel member scores. This is congruent with Delphi methodology.

If a panelist with a response outside the consensus range (more than two points higher or lower than the modal rating) wished to leave the response unchanged, they were asked to state their reasons for not changing and include them with the Delphi III. Space was provided on the reverse side of each page for respondents to give comment. At the conclusion of this final review the panelists were instructed to return the scale report, with or without changes made.

The revised values assigned by the panelists in Delphi III were used to compute Q-values and median scores. Q-values, indicating the interquartile range, were computed for use as an indication of agreement among panel members on a given item. Consensus, as used in this study and supported through previous research (Thurstone, 1929; Copeland, 1977; Barnes, 1987; Croft, 1990), is defined as those items, rated on an eleven point scale, having Q-values equal to or smaller than 4.00. Items with Q-values larger than 4.00 indicate that experts have diverse opinions concerning their inclusion within a specific knowledge area. Those categories with calculated Q-values equal to or lower than four indicated strong agreement among experts concerning their inclusion.

In addition to ascertaining consensus, it was equally important to calculate an acceptability level for determining if an item should be included in a list of subdivisions considered important to biotechnology instruction. At the outset of this study experts in the field of biotechnology were requested to supply subdivisions they considered important to the study of biotechnology. As such, it was anticipated that the resultant lists would be composed of items initially bearing high importance. It followed then that ratings would be relatively high, necessitating a large range of acceptability. With the expectation of high item scores the 25th percentile was chosen as a suitable, lower end cut-off point for determining acceptance. A frequency distribution comprised of all median scores was constructed to locate the 25th percentile.

Results

The Delphi I instrument asked the twenty panel members for their response to two questions. The first question asked them to designate main biotechnology knowledge areas. Titles received from the Delphi I were initially grouped according to content similarities. For example, the titles “Genetic Engineering,” “Genetics,” and “Genetics & Genetic Engineering” submitted by three different panel members, were all placed within a single column because they represented a knowledge area of analogous characteristics.

Grouping of main knowledge areas was further refined by looking for similarities in subdivisions panel members chose to be included under a given title. For instance, the main knowledge area titles of “Traditional Biotechnology,” “Microbiology,” and “Microbial Applications” all contained subdivisions labeled fermentation, products of fermentation, fermentation technology, types of organisms, etc., and were therefore understood to be referring to similar processes, calling for all to be placed in the more general category of bioprocessing.

Nineteen of the twenty panel members (95%) returned a fully completed Delphi I instrument. An analysis of the data showed eight distinct biotechnology knowledge areas in the panel members' responses. Those eight knowledge areas, validated by the local committee, are shown in Table 1.

Table 1
Main Biotechnology Knowledge Areas

1.	Bioprocessing
2.	Foundations of Biotechnology
3.	Genetic Engineering
4.	Agriculture
5.	Biochemistry
6.	Medicine
7.	Environment
8.	Bioethics

A total of 446 unique subdivision titles were submitted by the panelists, from which a list of 84 primary titles was derived. The eight main knowledge areas and subdivision titles were used to construct the Delphi II instrument. This initial list of biotechnology knowledge areas and respective subdivisions can be found in Table 2.

The second round instrument asked panel members to rate the subdivisions, using an eleven point scale, with regard to the level of importance for their inclusion in the final taxonometric structure. Ratings by panel members for each of the eighty-four subdivisions were entered into a statistical file and calculations were made to determine the mode, median, and Q-value for each. Calculated median scores for all eighty-four subdivisions were used to construct a frequency distribution for locating the 25th percentile cut-off score. This cut-off score was determined to be 8.5. Thus, median scores for each subdivision equal to or greater than 8.5 were considered at a sufficient level of importance to be included in the taxonomy. Q-values were also calculated from the Delphi II data to determine the degree of consensus on the rating given to a subdivision. Table 2 contains a summary of Delphi II responses, listing the subdivisions by main knowledge area and rank ordered according to median scores.

Table 2
Summary of Delphi II Ratings

Rank	Knowledge Area & Subdivision	Mo	Mdn	Q
	BIOPROCESSING			
1	Fermentation	11	10.5	1.0
2	Culturing	10;11*	10.0	1.0
3	Microbial Applications	11	10.0	2.0
4	Genetic Engineering	11	10.0	2.0
5	Social Impact	11	10.0	5.0
6	Bio-Products	9	9.0	1.0
7	Types of Microorganisms	9	9.0	2.0
8	Separation & Purification Techniques	11	9.0	4.0
9	Microbial Structure	9	9.0	3.0
10	Processing Design: Monitoring & Growth	10	8.5	3.0
11	Biomass Conversions	8	8.0#	2.0
12	Bioprocessing of Fossil Fuels	8	8.0#	2.0
13	Processing Types	8	8.0#	2.0
14	Bioreactor Design	7	7.5#	3.0
15	Historical Overview	7	7.0#	3.0
16	Bioelectronics & Bioworks	5	6.5#	3.5
17	Packaging	1; 6*	5.5#	4.5
	FOUNDATIONS IN BIOTECHNOLOGY			
1	Laboratory Safety	11	10.0	1.0
2	Social Impact	11	11.0	2.0
3	Scientific Method	11	10.0	4.0
4	Definition of Biotechnology	11	9.0	5.0
5	Historical Background	8; 11*	8.5	3.0
6	Relevant Terms	9	8.5	4.0

Table 2 (cont.)
Summary of Delphi II Ratings

Rank	Knowledge Area & Subdivision	Mo	Mdn	Q
7	Career Information	9; 11*	8.5	4.0
8	Specifications on Lab Journals and Logs	8; 10*	8.0#	3.0
9	Career Preparation	8; 9*	7.5#	4.0
10	Profiles of Biotechnology Companies	5-9*	6.0#	3.0
	GENETIC ENGINEERING			
1	Genetic Code	11	11.0	1.0
2	Social Impact	11	11.0	3.0
3	Analysis of DNA	11	10.0	1.0
4	Vector Systems	10; 11*	10.0	1.0
5	Probing Techniques	10; 11*	10.0	2.0
6	Molecular Biology Techniques	11	10.0	2.0
7	Basic Structure of Genetic Material	11	10.0	2.0
8	Genetic Engineering Applications	11	10.0	2.0
9	History and Ethics	11	10.0	2.0
10	Basic Research	11	9.5	4.0
11	Basic Cell Structure	11	9.0	4.0
12	Genome Projects	10	9.0	4.0
13	Marine Biotechnology	7-10*	8.0#	3.0
	AGRICULTURE			
1	Tissue Culturing	11	10.5	2.0
2	Plant & Animal Genetic Engineering	11	10.0	2.0
3	Microbial Applications	10	10.0	1.0
4	Plant & Animal Applications	10	10.0	0.0
5	Social Impact	11	10.0	2.0
6	Plant Physiological Systems	11	9.5	3.0
7	Agrichemicals	10	9.0	3.0
8	Animal Physiological Systems	10	9.0	3.0
9	Food Safety	8	8.5	2.0
10	Aquaculture	10	8.5	3.0
11	Food Science	9	8.0#	3.0
12	Food Packaging	8	7.0#	3.0
	BIOCHEMISTRY			
1	Proteins	11	10.5	2.0
2	Enzymology	11	10.0	2.0
3	Control and Regulation	11	10.0	2.0
4	Methods of Analysis	10	10.0	3.0
5	The Genetic Material	10; 11*	10.0	2.0
6	Macromolecular Structure	11	9.5	3.0

Table 2 (cont.)
Summary of Delphi II Ratings

Rank	Knowledge Area & Subdivision	Mo	Mdn	Q
7	Social Impact	11	9.5	5.0
8	Carbohydrates	9	9.0	2.0
9	Lipids	8	8.5	2.0
	MEDICINE			
1	Social Impact	11	11.0	1.0
2	Immunology	11	10.0	2.0
3	Genetic Therapeutics	10	10.0	1.0
4	Molecular Medicine	11	10.0	2.0
5	Health Care Technologies	10	9.0	2.0
6	Medical Devices	8; 10*	8.0#	3.0
	ENVIRONMENT			
1	Social Impact	11	11.0	1.0
2	Biological Controls	10	10.0	2.0
3	Bioremediation	11	10.0	2.0
4	Biotreatment Systems	11	10.0	2.0
5	Biorestoration	10	10.0	1.0
6	Safety	10; 11*	10.0	3.0
7	Wildlife Management	8	8.0#	5.0
	BIOETHICS			
1	Social Impacts	11	11.0	1.0
2	Principles of Ethics	11	10.0	2.0
3	Impacts of Using Biotechnology	11	10.0	2.0
4	Regulation: Legislation & Safety	11	10.0	2.0
5	Potentials of Gene Therapy	11	10.0	2.0
6	Patenting of Life	11	9.5	3.0
7	Forensics	9	9.0	2.0
8	Technology Transfer	8; 10*	8.5	3.0
9	Population Studies	7	8.0#	2.0
10	Timetable for Development	4; 7; 8*	6.5#	4.0

*Multiple modal points #Median score below cut-off

The data gathered in the second round provided an initial indication of consensus concerning subdivision level of importance, leading to their eventual inclusion in, or exclusion from, the final taxonometric structure. These second round results showed a small portion of the subdivisions falling below the median cut-off point of 8.5. The seventeen subdivisions rated below the cut-off point for median scores are indicated in Table 2 by the “#” symbol next to the median score.

Delphi III was a modification of the second round instrument. Included in the third round instrument were additional components to allow panel members to (a) view their rating positions relative to the other experts, and to (b) adjust their previous rating if swayed by the majority response, or by arguments from the comments submitted by other panelists. Modal positions for each subdivision were circled on the Delphi III instrument to indicate majority opinion, giving panel members a reference point for their ratings relative to the group.

Overall, the data returned in the Delphi III revealed relative standings for the eight main biotechnology knowledge areas. These standings were viewed with respect to the degree of agreement reached (Q-values) concerning the level of importance (median scores) bestowed on individual subdivisions within each knowledge area. Ranked by “percent subdivisions rated above the median cut-off point,” the main knowledge areas of *Biochemistry* and *Medicine* proved to be highest. Lowest in the standings, with only 59% of its total subdivisions rated above the cut-off point, was the *Bioprocessing* knowledge area.

The response data gathered from Delphi II, gave early indication of a large degree of consensus by panel members on which subdivisions were considered important for adequate instruction of biotechnology at the secondary school level. Only seventeen out of the total of eighty-four subdivisions were not considered important enough for inclusion within one of the eight main biotechnology knowledge areas. This represented 20% of the total population of subdivisions rated in this study. In the same comparison of Delphi III data, the percent of excluded subdivisions dropped slightly. In Delphi III, only fourteen of the eighty-four subdivisions remained below the acceptable level of importance, representing approximately 17%.

This general shift toward consensus among panel members regarding which subdivisions should be used for the instruction of biotechnology is readily apparent when both Delphi II and Delphi III data are compared. In all eight main biotechnology knowledge areas there was movement toward both a higher rating and greater consensus on the degree of importance for nearly every subdivision. The most marked shift within the eight knowledge areas was found in that of *Biochemistry*, where 76% of its nine subdivisions showed an elevated rating and a higher level of consensus. However, the general trend to shift subdivisions upward in the level of importance was consistent across all main knowledge areas. Table 3 summarizes the data comparisons between Delphi II and III, illustrating the trend to shift subdivisions upward along the scale of importance, and also the general strengthening of consensus revealed in the downward shift of mean Q-values in each main knowledge area. Only those subdivisions at or above the acceptable 8.5 median cut-off point are included.

Table 3
Summary of Trend Toward Higher Acceptable Ratings from Delphi II to III

Knowledge Area and Subdivisions	Rating Level D-II	Rating Level D-III	Mean Q-Value D-II	Mean Q-Value D-III	%Upward Shift
BIOCHEMISTRY			3.2	2.0	76%
Proteins	10.5	11.0			
Social Impact	9.5	11.0			
Control and Regulation	10.0	11.0			
Macromolecular Structure	9.5	10.5			
The Genetic Material	10.0	10.0			
Methods of Analysis	10.0	10.0			
Enzymology	10.0	10.0			
Carbohydrates	9.0	9.0			
Lipids	8.5	9.0			
MEDICINE			1.83	1.33	67%
Social Impact	11.0	11.0			
Molecular Medicine	10.0	11.0			
Immunology	10.0	10.5			
Genetic Therapeutics	10.0	10.0			
Health Care Technologies	9.0	10.0			
AGRICULTURE			2.25	1.75	67%
Tissue Culturing	10.5	11.0			
Plant & Animal Genetic Engineering	10.0	11.0			
Social Impact	10.0	11.0			
Microbial Applications	10.0	10.0			
Plant & Animal Applications	10.0	10.0			
Plant Physiological Systems	9.5	10.0			
Animal Physiological Systems	9.0	10.0			
Agrichemicals	9.0	9.0			
Food Safety	8.5	9.0			
Aquaculture	8.5	9.0			
Food Science	8.0	9.0			
GENETIC ENGINEERING			2.23	1.77	62%
Genetic Code	11.0	11.0			
Social Impact	11.0	11.0			
Analysis of DNA	10.0	11.0			

Table 3 (cont.)

Summary of Trend Toward Higher Acceptable Ratings from Delphi II to III

Knowledge Area and Subdivisions	Rating Level D-II	Rating Level D-III	Mean Q-Value D-II	Mean Q-Value D-III	%Upward Shift
Genetic Engineering					
Applications	10.0	11.0			
History & Ethics	10.0	11.0			
Basic Structure of Genetic Material	10.0	10.5			
Basic Cell Structures	9.0	10.5			
Vector Systems	10.0	10.0			
Probing Techniques	10.0	10.0			
Molecular Bio Techniques	10.0	10.0			
Basic Research	9.5	10.0			
Genome Projects	9.0	10.0			
BIOETHICS			2.3	1.70	60%
Social Impacts	11.0	11.0			
Principles of Ethics	10.0	11.0			
Impacts of Using Biotechnology	10.0	11.0			
Regulation: Legislation & Safety	10.0	11.0			
Potentials of Gene Therapy	10.0	11.0			
Patenting of Life	9.5	10.0			
Forensics	9.0	9.0			
Technology Transfer	8.5	9.0			
BIOPROCESSING			2.59	1.53	41%
Fermentation	10.5	11.0			
Culturing	10.0	11.0			
Genetic Engineering	10.0	11.0			
Microbial Applications	10.0	10.5			
Social Impact	10.0	10.5			
Separation & Purification Techniques	9.0	10.0			
Bio-Products	9.0	9.0			
Types of Microorganisms	9.0	9.0			
Microbial Structure	9.0	9.0			
Processing Design: Monitoring & Growth	8.5	9.0			

Table 3 (cont.)
Summary of Trend Toward Higher Acceptable Ratings from Delphi II to III

Knowledge Area and Subdivisions	Rating Level D-II	Rating Level D-III	Mean Q-Value D-II	Mean Q-Value D-III	%Upward Shift
FOUNDATIONS IN BIOTECHNOLOGY			3.3	2.1	40%
Laboratory Safety	10.0	11.0			
Social Impact	11.0	11.0			
Scientific Method	10.0	10.0			
Definition of Biotechnology	9.0	9.5			
Historical Background	8.5	9.0			
Relevant Terms	8.5	8.5			
Career Information	8.5	8.5			
Specifications on Lab Journals and Logs	8.0	8.5			
ENVIRONMENT			2.29	1.71	14%
Social Impact	11.0	11.0			
Biotreatment Systems	10.0	10.5			
Biological Controls	10.0	10.0			
Bioremediation	10.0	10.0			
Biorestoration	10.0	10.0			
Safety	10.0	10.0			

Mean Q-values in all eight knowledge areas decreased from Delphi II to Delphi III. This represents a decrease in the interquartile range, indicating a stronger consensus among the panel members for the appropriate level of importance rating given to each subdivision. When the eight knowledge areas are analyzed cumulatively, the move toward consensus is made clearer. The overall mean Q-value for the subdivisions rated in Delphi II was Q(avg.)= 2.45, with a standard deviation of 1.17. In comparison, the overall mean Q-value for the Delphi III data set was Q(avg.)= 1.74, with a standard deviation of .58.

The above calculations, and those given in Table 3, show (a) an overall increase in the level of importance ratings, (b) a marked decrease in average interquartile range, and (c) an overall average decrease in the standard deviation between responses given in Delphi II and Delphi III.

The main biotechnology knowledge areas and their respective subdivisions shown in Table 3 are the final list of knowledge areas and respective subdivisions identified by the panel of biotechnology experts participating in this study as those most appropriate for inclusion in a biotechnology taxonometric structure developed for the secondary school level.

Discussion

The eight main biotechnology knowledge areas identified in this study were found to effectively encompass the subject matter of biotechnology, and constitute the first level in a taxonometric structure for biotechnology at the high school level. The sixty-nine subdivisions with acceptable ratings were distributed among the eight main knowledge areas at varying levels of importance. It was evident from the data that some subdivisions were perceived to be of greater importance than others. The knowledge area with the largest percentage (50%) of subdivisions receiving a rating of 11.0 was *Bioethics*. This suggests that panel members view the subdivisions of this knowledge area as an extremely accurate representation of what should be addressed in *Bioethics*. This indicates that there is a great deal of certainty concerning the importance of these five particular subdivisions by a large majority of the experts. The same can be said for the 19 subdivisions in the seven other main knowledge areas that received ratings of 11.0.

This data implies that a larger number of those subdivisions used in *Bioethics* were perceived to be notably more critical for that knowledge area than were those submitted for the other seven knowledge areas. Along this same line of reasoning, *Bioprocessing* contains the largest percentage of its subdivisions, compared to the seven other main areas, below the median cut-off point of 8.5. The implication here is that a comparatively large portion of those subdivisions submitted for inclusion in *Bioprocessing* were not perceived critical to instruction in this area. In short, a greater majority of subdivisions submitted for the knowledge area of *Bioethics* more closely fit that area of instruction than did those submitted for the other seven. The opposite was found true for the knowledge area of *Bioprocessing*.

The dispersion in subdivision ratings was relatively small in six of the eight main knowledge areas. The percentage of subdivisions rated at the high end of the scale, between r = 10.0 and 11.0, was above 50% for the following main knowledge areas: *(a) Genetic Engineering (92%), (b) Environment (86%), (c) Medicine (83%), (d) Biochemistry (78%), (e) Bioethics (60%), and (f) Agriculture (58%)*. This indicates that the subdivisions in the main knowledge areas are highly accurate in representing the categories of greatest importance when addressing these main areas of biotechnology at the high school level. Moreover, the strength in accuracy is further indicated by how large the percentage of subdivisions are at the high end within a main knowledge area. Specifically, *Genetic Engineering*, with 92% of its subdivisions rated between 10.0 and 11.0, shows it to be the main knowledge area generating the strongest consensus. *Environment* and *Medicine* run close behind, with 86% and 83% of their subdivision, respectively, rated at the high end.

Of the 24 most highly rated subdivisions across the eight knowledge areas, one was common to all. *Social Impact* was rated at 11.0 in all but one knowledge area. It was given a rating of 10.5 in the one outstanding area. The perceived need for instruction on the current and potential impacts biotechnology can have on society was clearly evident among the panel members.

The identified list of knowledge areas and subdivisions serves as a foundation from which to continue developing appropriate biotechnology curriculum for students at the secondary school level. Table 3 presents the final list of knowledge areas, with their corresponding subdivisions rank ordered by Delphi III median scores. The use of this list by educators in technology education or biological sciences is likely to differ according to the approaches to curriculum development and delivery of instructional content within the classroom setting. These alternate uses stem from philosophical differences between science and technology.

Individuals in the field of technology education look to apply knowledge, using technical means, in developing solutions to practical problems. The emphasis is on practice, with processes centered around designing, creating, applying, and ultimately leading to a final outcome that is of practical use. This is in contrast with those in the field of science, biological or otherwise, who strive to understand natural laws and phenomenon through observation and use of the scientific method of investigation. In science the emphasis is on theory, looking to know and understand through observation, discovery, and experimentation in an effort to find a theoretical use for the information gained. The initial biotechnology curriculum taxonomy derived through this research is applicable in both of these approaches. The following example illustrates how this may be accomplished.

In the *Bioprocessing* knowledge area one of the highest rated subdivisions is titled “Fermentation.” It is expected that individuals in technology education would approach this topic in a very applied sense. Fermentation might conceivably be viewed as a componential process utilized in a larger system, only a part of which employs living organisms to produce a product or perform a service. Students would make use of the knowledge that yeast cells oxidize sugar molecules, and in a controlled environment can be made to produce a gasoline substitute such as ethanol. Their efforts might then be directed at the system as a whole, designing it to address a specific need. For example, in the alternative fuels industry efforts continue toward the developent of increasingly efficient means of producing gasoline substitutes. One area within which to increase efficiency is in developing methods for continuous fermentation using an immobilized cell process. The underlying principle is that yeast cells, imbedded within porous beads and submerged in a sugar solution, can still act on the sugar molecules while remaining separate from the solution. This immobilization of the yeast cells provides for quick separation and continuous production of end product, reducing production time and costs.

Understanding the environmental and biological requirements yeast cells have for fermentation to proceed, a method of cell immobilization in gelatinous beads could be designed. In approaching this problem students would need to take into consideration such parameters as 1) selection of the carrier - type of gelatin, 2) design of the reactor and shape of the carrier, 3) selection of the most appropriate yeast strain, 4) prevention of contamination, 5) maintenance of yeast viability, and 6) scaleup methods. This design process incorporates the utilization of a biotechnical process as a component of a larger system.

In contrast with technology education, biological science looks to understand the natural world through investigation into and observation of natural laws and phenomenon. Therefore, in approaching this problem biological science instructors might have students focus more on the mechanisms of oxidation that are involved with the variety of known fermentation processes. Using the scientific method of inquiry students would look to understand how fermentation by certain fungi and bacteria leads to the production of citric and gluconic acids, vitamins such as B_{12}, or some amino acids. The emphasis would be to gain knowledge of the biological methods of fermentation, possibly with the intent of looking for points where the process could be controlled or biologically enhanced.

These examples demonstrate how the same content can be addressed by both the biological science students and technology students, but the context would be markedly different. Based on the taxonometric structure identified in this study, instructional objectives developed for teaching biotechnology courses in technology education and biological science would differ in approach, yet remain centered around a consistent content. As such, they would be ideal for courses run in tandem or parallel. Sequencing of topics to be addressed and coordination of lessons would allow for delivery of fundamental bioscience knowledge in one course, and its biotechnical application in the other.

Biotechnology has come to be viewed as a set of powerful tools based on the knowledge and use of biological systems. Informed use of these tools is imperative, as endeavors in this field will ultimately touch every facet of American life from the water we drink and the food we eat, to the energy driving our machines and the materials used to produce them. The impact, both realized and potential, of biotechnology on our society has spurred efforts to introduce the basic concepts of this field into secondary school instruction. Contemporary technology educators, keenly aware of a natural place within their instructional objectives for the study of biotechnology, are moving to include it within the technology education instructional program. The taxonomy derived through this research would allow for future development of secondary biotechnology curriculum, applicable within either a technology education program or biological sciences program.

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