ESTABLISHMENT OF A TAXONOMETRIC STRUCTURE FOR THE STUDY OF BIOTECHNOLOGY AS A SECONDARY SCHOOL COMPONENT OF TECHNOLOGY EDUCATION

by

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Establishment of a Taxonometric Structure for the Study of Biotechnology as a Secondary School Component of Technology Education

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(ABSTRACT)

This research endeavor focused on the establishment of the first two hierarchical levels in a taxonometric structure for biotechnology. The taxonomy was developed in response to the lack of an agreed upon curriculum structure for incorporating biotechnology at the secondary school level.

The purpose of the study was to provide educators with a viable taxonometric structure for the development of biotechnology curriculum, applicable within both a technology education program or biological sciences program. As the field of modern biotechnology is still in its infancy, an unstructured, characteristic-retaining variation of the Delphi technique was used as the methodology for this investigation.

The 18 member Delphi panel consisted of biotechnology experts from four sources: (1) educational organizations, (2) biotechnology companies, (3)

universities, and (4) government agencies. The Delphi I instrument was directed at ascertaining opinions on (a) what main knowledge areas describe biotechnology, and (b) what subdivisions comprise each of those areas. Delphi II and Delphi III asked panelists to rate, using an eleven point Likert-Type scale, the subdivisions identified in Delphi I. Median scores and Q-values were used in analyzing the data. Q-values determined the level of agreement among panelists and provided a dispersion estimate of their opinions. Using this method, the level of consensus among experts on opinions toward inclusion of an item in a given knowledge area was reached. A frequency distribution using all median scores was constructed to determine the 25th percentile score. This score was used as the cut-off point for determining acceptance of a subdivision as important for thorough instruction in biotechnology.

The study identified and showed consensus among the experts on eight main biotechnology knowledge areas, with a total of eighty-four subdivisions distributed among them. These knowledge areas and their accompanying subdivisions comprised the first two hierarchical levels in a taxonometric structure for biotechnology at the secondary school level.

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CHAPTER I THE PROBLEM

Biotechnology will be changing and shaping our society for decades to come. If asked to explain the meaning of this term, the average citizen, and even a great many scientists, would be hard pressed to give an adequate definition. This confusion stems from the wide variation in definitions used by the many evolving biotechnology industries to describe their methods of application (Office of Technology Assessment, 1988). For this study, and eventual use at the secondary level, the term *biotechnology* is defined as follows, taking into account both old and new techniques:

> biotechnology...includes 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).

Current developments in biotechnology are proceeding at accelerated rates similar to the microelectronics boom of the 1970s. However, the myriad prospects offered through R&D in biotechnology far exceed that of even the silicon microchip. The advent of a modern biotechnology revolution was sparked less than twenty years ago, and is clearly underway at the onset of

this decade (Henderson and Knutton, 1990; Smith, 1988; Ouellette and Cheremisinoff, 1985).

The growth and awareness of modern biotechnology has been stimulated by past and present crises affecting people in all corners of the globe. The elucidation of the DNA molecular structure by Watson and Crick (Watson and Crick, 1953) provided the springboard for developing techniques to manipulate the genetic material of an organism. Today these genetic engineering techniques affect industries from medicine to metallurgy, and offer potential benefits to human life limited only by the extent of human imagination.

Global confrontations in the early 70s resulting from oil embargoes brought about the undeniable realization of limitations on future fossil fuels, and the need for cheaper, more secure forms of renewable energy supplies. The advances in molecular genetics and associated technologies paralleling these worldwide disruptions pointed to an emerging field called biotechnology as an area of research with viable solutions to the problems (SCANS, 1991; Smith, 1988).

The R&D of the 1990s continues with strong indications that modern biotechnology methods can utilize new raw materials, and alleviate many of the problems currently surrounding the production of such necessary commodities as fuel, feed and food (Roa, 1986). However, the explosive impact of

biotechnology on the medical field has, by far, had the greatest impact on creating heightened public awareness of its effects on their everyday lives.

Advancements in diagnosis, prevention and treatment of cancers and diseases of the heart show encouraging progress for ways of combating these deadly diseases. Vaccines never before available can protect against major viral diseases that in the past took the lives of hundreds of people each year. Rapid diagnostic tests, normally administered by a physician, are now available to the general public for home use. These, and a great many more marvels, are resulting in a steady increase in civic awareness of the dramatic economic and social repercussions biotechnology may have on society (Project 2061 Panel Report, 1989; Smith, 1988; Prentis, 1984).

In light of these past and present trends, biotechnology has come to be viewed as a significant component for the restimulation of various economies, both from a local and global perspective. Its prominent position has drawn extensive media attention, stimulating a steady rise in public awareness concerning its importance and future effects on society.

Biotechnology is a modern 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 within 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 (Wise, Buonopane, and Blackman, 1990; Project 2061 Panel Report, 1989; Gayford, 1987; Royal Society, 1982). However, these initial attempts are taking place strictly 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.

In 1981 a curriculum effort, funded through a grant from the Technical Foundation of America, culminated in a document known as the *Jackson's Mill Industrial Arts Curriculum Theory* which had a major influence on the direction of the profession (Snyder and Hales, 1981). This document provided a rationale and conceptual structure in use today by the technology education profession, and designated transportation, communication, construction and manufacturing as content organizers. The Jackson's Mill document was a

conscious effort to describe the mutual interaction between knowledge and adaptive systems of technology and industry, and sought to classify the components of human endeavor in a meaningful way for delivery in an instructional setting. 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). The strongest support for this move was recently 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 document, 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). Indeed, bio-related technology is expressly recommended as one of the four content organizers, along with communication technology, production technology and transportation technology.

This move toward an increased understanding of the technical applications of life processes needs to be approached from the standpoint of the new technologies and biological systems used to that end (Wells, 1991). 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 (DeVore, 1966).

The profession recognizes the importance of including biotechnology within its discipline, and is poised to put forth the efforts required for this task. But in order for curricula and instructional programs in biotechnology to be developed, initial agreement on the content structure must be attained.

Purpose

A problem facing general high school education is the absence of an agreed upon curriculum structure for incorporating the instruction in biotechnology at the secondary level. This research was performed in response to that need. An effort to reach consensus by a panel of experts on primary components of such a structure, as might be included in a technology education program, is the direction of this study. The purpose of this study was to develop a conceptual model of the first two 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.

Research Question

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?

Delimitations of the Study

The delimitations of this study were:

1. The structure established in this study was intended as a guide to be used in curriculum development.
2. The categories of biotechnology knowledge derived through this study were delimited to their use in determining a biotechnology taxonometric structure at the secondary school level.
3. The developmental extent of the taxonometric structure was delimited to first and second hierarchical order knowledge categories.
4. The study was delimited to experts selected from (a) educational organizations, (b) biotechnology companies, (c) universities, and (d) government organizations.

Assumptions

This study is based on the following assumptions:

1. Utilization of taxonometric principles provides a base for establishing a definitive curriculum structure for the study of secondary school level biotechnology.
2. Recognized experts used in this study were qualified to identify the knowledge categories for a secondary school biotechnology curriculum taxonomy.

Definition of Terms

To promote clarity and consistency in understanding, the following definitions of terms are provided:

1. *Biotechnology.* 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).
2. *Technology.* The study of the application of knowledge, creativity, and resources to solve problems and extend the human potential (Technology Education Advisory Council, 1988).
3. *Technology Education.* The school program whose curriculum is directed at the study of technology (Savage and Sterry, 1991).

4. *Taxonomy.* The classification of knowledge areas as a source of constructive assistance in the organization of structural elements of education (Bloom, 1956).

Summary

The impact of the biotechnology revolution is an inescapable reality that permeates nearly every aspect of human existence. In a broad sense, biotechnology is seen as the applied knowledge of biological processes for industrial and technological purposes (Rao, 1986). The term is a new name describing a mixture of both new and old technologies. It is the burgeoning of these newer technologies within the past ten to twenty years that has given biotechnology a prominent position in current world affairs. The potential benefits in a variety of industries - health, food, energy, environmental, pharmaceutical, etc. - are immense, but will carry potential disadvantages as well.

Any major emerging technology has profound social and economic effects. Biotechnology is no exception, and will have a direct and personal impact on human life and health. It is therefore of particular importance that young adults be made aware of the scientific principles that govern the advances being made in biotechnology and to prepare them suitably to face the challenges that await them. To this end, the present study was directed at establishing a

taxonometric structure for the future development of secondary school biotechnology curriculum.

CHAPTER II REVIEW OF LITERATURE

Introduction

"Knowledge will forever govern ignorance: And a people who mean to be their own Governor, must arm themselves with the power which knowledge gives" (James Madison, 1822).

Preparatory to this study was a review of literature relative to the issue of developing a biotechnology taxonomy for instruction at the secondary level. This chapter presents that review, delivering what is felt to be the essential foundation for this study. A combination of renewed nationwide emphasis on science, math and technology education, the exponential growth and civic impact of modern biotechnology, and the desire for U. S. industries to remain among world leaders in technology, are all compelling reasons for the *inclusion* of biotechnology in secondary education. To do so will require a knowledge structure, a taxonomy, from which to derive the curriculum. At present there exists little formative research in secondary education toward that end.

Through a synthesis of the literature reviewed, four topics were found necessary to fully comprehend and convey the overall picture surrounding this issue: (1) the influence of science and technology on educational curriculum

development, (2) the emergence and impact of modern biotechnology, (3) taxonometric structures in curriculum development and (4) the Delphi technique as a method of achieving consensus. These topics present a logical flow of interrelated events leading to both the perceived and real need to establish a taxonometic structure for curriculum development of modern biotechnology at the secondary school level.

Science and Technology: Influences on Curriculum

When viewed as the agent through which the aims, purposes and objectives of education are obtained, the curriculum is the most elemental structural component of education (DeVore, 1966). The development of that curriculum is a principle task that must be constantly addressed by those involved with any aspect of formal education. Requisite to that development however, is some force that compels a demand for change. The strongest of such forces are those pertaining to societal requirements, both real and/or perceived.

At the most basic level, policies and practices of governments and institutions have the greatest influence on the educational system (Altbach, 1985; Boulding and Senesh, 1983). In effect, many of society's needs, educational and otherwise, are displayed through federal policy. The evidence of such societal influences on education are clearly visible in the curricular

movements beginning around the sixth decade of this century. The major forces found to initiate those movements, with regard to the perceived purpose of education, were social reactions to one or more of four general situations: (1) a response to outside forces (2) the need for providing moral and social training, (3) the need for providing equality of opportunity, and (4) the need to educate future citizens (Doyle, 1991; Altbach, 1985; Spring, 1985). These forces proceeded to shape the direction of education throughout the ensuing decades and continue in the present one.

Historically, major efforts toward curricular change are seen coupled to significant events affecting the social needs of the nation. It is of note that the perceived importance of science, math and technology, relevant to the event, has been componential with each critical curriculum movement (Layton, 1986). A brief overview of those events occurring over the last thirty years points out that relevance, and is pertinent to providing the context from which this study stems.

The 1960s

Russia's placement of Sputnik into Earth orbit in 1957 caused a national frenzy. Ultimately, the educational system was perceived as the source of America's inability to compete with advances in Russian space technology. There followed a massive effort to revitalize education, with the essential

changes in curriculum focused on increasing the quality of science, math and technology instruction, and improving public understanding and appreciation of those subjects (NDEA, 1957; Cooley, 1959).

Federally funded developmental curriculum projects of the 1950s and 60s were the result of this crisis, and the starting point for direct federal influence in education. The first of these projects was the Physical Science Study Committee (PSSC), headed by Dr. Jerrald Zacharias, that strove to design a high school physics course through a group effort. From late 1957 to the mid 1960s a number of similar curriculum development projects were initiated: the Biological Science Curriculum Project (BSCS), the School Mathematics Study Group (SMSG), the Chemistry Education Materials Study (CHEM), the Earth Science Curriculum Project (ESCP), and the Industrial Arts Curriculum Project (IACP). Each project was approached using the same basic developmental methodology, differing from earlier curriculum efforts which focused primarily on the textbooks and instructor's guides as tools for effective teaching of those texts. (Grobman, 1970).

The last project mentioned, the IACP, was specifically directed at the technologies of industry. It began in 1966 with the purpose of developing a structure for the body of knowledge which they defined as industrial technology (Towers, Lux, and Ray, 1966). The wide-scale acceptance of this, as well as the other innovative curriculums mentioned, is largely attributed to

the integration of learning materials and teacher variables (LaPorte, p.33, 1980).

The "developmental" approach used in these innovative curriculum projects was a progressive move to cause institutional changes in the delivery of science, math and technology instruction. This method relied on the efforts of a group (as opposed to an individual or coauthor) to produce a new curriculum, and was combined with field testing of preliminary materials to gather feedback information for making improvements (Grobman, 1970). This 1960s methodology, still employed in various forms today, is central to the developmental approach used in this study.

The 1970s

Social problems begun in the 1960s carried over into the 1970s. The struggle for racial equality, a changing job market, high unemployment, and the desire to end poverty, all brought about another wave of educational reformation. The change resulted in schools modifying their curriculums to address the need for adjusting to massive social change. The general emphasis in education was now to end poverty by educating the poor, generate career awareness, and to prepare an industrial work force. This was attempted by making curricular changes to meet those goals (Spring, 1985).

The end of the decade found education's focus on social problems changing to one concerning the American economy. This change was in response to a nation experiencing a decline in productivity and dwindling capital investment by American industry. The shift created a "back to basics and return to excellence" movement, involving a renewed interest in science, math and technology (Altbach, 1985).

The 1980s & 90s

In the 1980s schools had come to be viewed as institutions of fundamental importance to the country's political and economic balance. During this decade the nation found itself in the middle of rapid social and economic shifts resulting from a barrage of technological advancements (Peterson, P., and Rabe, B., 1983). The educational system was once again seen as the change agent for the road to recovery, resulting in curriculum modifications to accommodate increased academic requirements in math, science and technology. The cry for excellence in education during the 80s is in many respects similar to the educational response to Sputnik and the stress on science in the 1950s (Ravitch, 1983).

However, unlike earlier curriculum reforms that addressed the sciences (math, science and technology) from an elitist standpoint, the educational reformation movement begun in the late 80s and currently sweeping the

country, shows the desire for a scientifically and technologically literate citizenry emerging as the important focus for future educational innovation. The major concern was no longer to create a pool of future technologists, but to educate the majority of non-technological, non-scientific people living in a technologically-based society (Project 2061, 1989; Unesco, 1983, p. 47).

The report from the Project 2061 Technology Panel, and numerous similar studies (Changing America: The New Face of Science and Engineering, 1989; A Nation At Risk, 1983; Action for Excellence, 1983; Boyer, 1983), made very clear the failings of American education to prepare the nation's youth for participation in a society where the technological and scientific knowledge base is rapidly and continually changing. At the federal level these reports sparked the establishment of the six National Education Goals, two of which can be shown to directly relate to the need for education in modern biotechnology:

GOAL #4: "By the year 2000, U.S. students will be first in the world in science and mathematics achievement."

Pertinent Objectives:

a) Math and science education will be strengthened throughout the system, especially in the early grades.

b) The number of teachers with a substantive background in mathematics and science will increase by 50 percent.

GOAL #5: "By the year 2000, every adult American will be literate and will possess the knowledge and skills necessary to compete in a global economy and exercise the rights and responsibilities of citizenship."

Pertinent Objectives:

a) Every major American business will be involved in strengthening the connection between education and work.

b) All workers will have the opportunity to acquire the knowledge and skills, from basic to highly technical, needed to adapt to emerging technologies, work methods, and markets through public and private educational, vocational, technical, work place, or other programs.

The emphasis on science and mathematics in Goal #4, directed both at students and teachers, and the reference in Goal #5 to acquiring knowledge and skills for adapting to emerging technologies, depends on many aspects of instruction in math, science and technology. The emphasis in those goals on the need for increasing educational excellence is further verified in numerous reports and studies. According to Dr. James R. Johnson, chair of the Technology Panel, Project 2061, substantial changes are necessary to

strengthen educational programs, particularly in science, math and technology. His gives two underlying reasons for making these changes:

* A technologically literate populace is necessary if citizens are to apply in a responsible manner their values and judgements in the control and use of technology.
* The nation needs outstanding, rigorously educated and trained young men and women to enter careers as engineers, scientists and technologists. (Johnson, 1990).

Of major import to the fulfillment of the National Education goals, and paramount with regards to this study, is the realized impact the present biotechnology revolution is having, and will continue to have, on the nations and peoples of the world. The scope of modern biotechnology, and the potential inherent to this technology are factors that will result in significant national and international effects on societies and industries, with no clear boundaries between them.

Why is this new technology emerging now? Why are the advances having such great impact on societies throughout the world? What changes will be wrought in current lifestyles? How pervasive will biotechnology be as it filters into the social systems? What benefits and/or hazards are in store from the

strides being made in biotechnology? What should the general public know about this technology? Answers to these queries will affect people today and those well into the future. Only through a sound understanding of the methods, processes, implications and potentials can the full extent of possibilities available from modern biotechnology be realized. Young people will need to know some of the underlying relationships basic science, math and engineering concepts have to this expanding technology.

The following section looks at the scope of contemporary biotechnology, conceivable social and industrial ramifications, the need for public awareness, and the implications these all have on developing the curriculum necessary for integrating biotechnology into secondary school education. The literature reviewed for this purpose was synthesized to establish the need in education for an agreed upon structure that describes the knowledge content of biotechnology. That knowledge structure is the initial step necessary for its future incorporation into the secondary school curriculum.

Modern Biotechnology: Emergence and Impact

Biotechnology was a part of human history long before the realization of its mechanics. 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. There currently exist two fields of biotechnology: traditional and modern.

Traditional biotechnology methods include those used in the manufacture of such things as fermented foods, beer, wine, bread and cheese. For the most part those methods are based on experience and tradition, and may or may not require scientific analysis or understanding. Of more recent origin, but still included with traditional biotechnology, is the production of antibiotics and vaccines. These processes made use of microbial organisms, and were based on sound scientific principles. Microbial organisms are also used in water purification and waste management, or in controlling the growth of unwanted organisms through aseptic methods. All the above mentioned are regarded as traditional or classic areas of biotechnology (Prentis, 1984; Office of Technical Assessment, 1988).

Over the last 30 years tremendous strides have been made in the understanding of molecular genetics, leading to extended capabilities in biotechnology. Beginning with the description of deoxyribonucleic acid (DNA) by James Watson and Francis Crick (Watson and Crick, 1953), scientists now understand how genetic information is stored in a cell, how that information is duplicated and how it is passed from cell to cell, from one generation to the next. Research into the isolation and recombination of DNA opened up a plethora of possible applications for this new technique. Monoclonal antibody

technology, bioprocessing technology, genetic engineering, and the technologies involved with the environmental controls associated with those methods, are but a few of what is now termed "modern" biotechnology (Prentis, 1984; Office of Technology Assessment, 1988).

Today, applications of both classic and modern biotechnological methods are diverse and numerous. According to the National Research Council (1982) and the Office of Technology Assessment (OTA) (1988), the administration of biotechnological methods holds great promise for finding solutions to many social and industrial problems in the following areas: vaccine production, energy production,fermentation processes, plant and animal genetics, monoclonal antibodies and agriculture. These areas belong to the growing array of biotechnology industries that much of the population has come to use and depend on.

Impacts on Industry and Society

According to the OTA (1988) the combined annual spending by U.S. industries in biotechnology research and development during 1987, was between 1.5 - 2.0 billion dollars. Estimates for the 1990s go far beyond that. Biotechnology has become such an essential tool for so many industries that it is difficult to delimit them. The breadth of possible commercial markets for biotechnology at times appears limitless. However, there appears to be eight

generally agreed upon biotechnology markets, or industrial areas found in the literature (Smith, 1988; Office of Technology Assessment, 1988; Prentis, 1984). A brief description of those eight markets follows:

(1) Chemical

Within the U.S., the chemical industry is a business generating revenues in excess of 100 billion dollars. It deals with the production of vitamins, amino acids, sweeteners, enzymes, fats and oil, aromatic compounds, and polysaccharides. Each of these areas impacts the health and welfare of the population, and has great economic potential.

(2) Pharmaceutical

The pharmaceutical sector of the economic market is vast. The areas dealt with include diagnostic tests using monoclonal antibodies and DNA probes, hormones and growth factors, antibiotics and therapeutic programs, all of which to some extent influence the activities of millions of people daily.

(3) Medical and clinical diagnostics

Projections for the medical and clinical diagnostics market show it far exceeding a billion dollars by 1993. Of that market, half will be represented by immunodiagnostics. The techniques involved utilize antibodies, enzymes and

cellular probes to detect and target conditions within the body. Examples range from home pregnancy testing to cancer treatments, with future applications seemingly endless.

(4) Animal health

Animal populations on the farms far exceeds that of the human population. This sector of biotechnology can be applied to animal growth production, nutrition and the genetic improvement of livestocks. It also is used in the prevention and control of diseases, and increased products yield and quality. Decreasing the loss of livestock to health problems has a direct effect on the economics of the food industry.

(5) Food and agriculture

The United States is called the food basket of the world, and for good reason. The food sector is one of the biggest segments of the U.S. economy, and the one most susceptible to consumer preferences and large scale social trends. In addition, this component of biotechnology is looked upon as a major force in curtailing global hunger. Nitrogen fixation, genetic manipulation of plant cells, new crop plants are important food and agricultural problems that can be managed with biotechnology.

(6) Energy production

The continued depletion of fossil fuel energy sources on a global scale creates a dire need to seek out alternative sources of energy. Within the biotechnology field these will take the form of biomass conversions, enhanced oil recoveries, and hydrogen (produced by photosynthetic bacteria, biophotolysis of water or fermentation) as a fuel. A growing appreciation of biological energy systems and biotechnological advances in this area, will soon bring economic success to these processes.

(7) Environmental protection

This realm of biotechnology is in line with the fundamental desire for health maintenance and an enhanced quality of life. Increases in the human population are generally matched by an ever growing variety and amount of waste products, many of which cause serious harm to the environment if allowed to accumulate. The development of specific waste treatment processes using biotechnology methods has resulted from the need to refrain from discharging high volumes of waste into natural land and waters.

(8) Supporting equipment and techniques

Biotechnology is interdependent on the quality of the technologies needed to control it. The design and scaling-up of fermenters, quality of reagents and

media, purification and separation techniques, and monitoring and control mechanisms are crucial to successful biotechnology systems.

Most of the developments previously outlined will have important implications for our future existence, whether we live in tropical or temperate conditions, in rich or poor countries, in urban or rural situations, and irrespective of the social background or standing of the people. Many people believe that the discoveries being made in biotechnology can significantly improve the quality of our lives. However, there is also the realization that intelligent use of this new knowledge depends on society's understanding of its potential and limitations.

Our ability to reach our potential, as individuals and as nations, depends critically on education. Technology's benefits can be fully realized only through an enlightened citizenry, and the public interest will be served best through a technologically literate population.

Instructional Aspects of Biotechnology

According to the Project 2061 Phase I Technology Panel report in 1989, the advances predicted for biotechnology during the next few decades will require specific education and training for individuals going into the biotechnology field. There will also be a concurrent need for greater public

awareness on the subject, with attention given to both the positive and negative consequences. This calls for an educational system with programs developed to provide adequate instruction on the subject. At present there exists such a fledgling system in the United States, operating at the university level.

Traditionally, the university system has been one in which the study of a vast assortment of specialized subjects was available. Yet it is only in the past few years that undergraduate degrees in biotechnology have become available. The 1988 assessment of new developments in biotechnology by OTA found more than 60 universities across the nation offering a biotechnology program, though most of those did not yet offer degree programs. Introduction of the subject at the secondary level is far less extensive.

Pressures at the secondary level on curriculum time alone, places limits on providing students with a variety of subjects in a broad and balanced educational experience. Given that, few in education might advocate the inclusion of biotechnology as a separate subject area. However, existing frameworks for high school curriculums developed within the last decade provide ample opportunity to incorporate biotechnology. Nevertheless, there are dangers in building the content of biotechnology strictly into the high school science syllabus, where the content is already enormous and its

complete coverage difficult. The technology education program, as an equally appropriate instructional environment, offers an excellent avenue for inclusion of biotechnology into the secondary curriculum.

The Technology Panel, Project 2061 (1989), established that technology should be incorporated into the present elementary and secondary school programs. It was the panel's belief that:

* Technology education should reveal the process of technology as it evolves from ideas to fruition.
* Technology education should be appropriate to the students' age and experience.
* Technology education that includes social impacts as well as the technics provides the opportunity to integrate the two in newly formulated curricula, possibly making increased use of team teaching.
* The sciences and mathematics are important to the understanding of the processes and meaning of technology. Their integration with the technology education curricula is vital.

In agreement with the panels belief statements, Ruggles (1990) further reasons for the specific inclusion of biotechnology within the field of technology education. He finds biotechnology represents an "input-process-output" system using biological processes for producing goods or services to

humans, which follows the current instructional model used in technology education programs. Other professionals in education also see the need and importance of this inclusion, and curricula development for biotechnology at the secondary level, in this country and abroad, is getting underway.

In Great Britain biotechnology has been of interest to the educational system since the early 1980s, when the Spink's Report (1980), the Royal Society report, *Biotechnology and education* (1981) and others like them, called attention to the growing importance of that area of technology. Though pointing out the economic importance of the field, the reports also emphasized an increased need for relevance of biotechnology in the science curriculum. The Education Reform Act (1988) recently introduced in the UK had as its central component, the implementation of a National Curriculum. Biotechnology is found in the National Curriculum under Technology, a core subject of Craft, Design and Technology (CDT) curriculum (Henderson and Knutton, 1990). Indicative of its new arrival on the scene, the attainment target dates for inclusion, at the high school level, of this program area in the CDT curriculum, is set for school year (SY) 1993/94 (DES, 1989).

The U.S. educational system has not yet made any overt step toward development of biotechnology for general high school students. A few scattered attempts are being made, with most targeted for integration into existing science programs. One such exploratory program has been

established by the engineering department at Northeastern University in Boston, Massachusetts (Wise, Buonopane, and Blackman, 1990). The underlying objective of their project was to determine how technology could be introduced into the high schools. Their choice of biotechnology as the conveyor theme was due, in part, to this new technology gaining a great deal of prominence with the media, and so of possible interest to students. More importantly though, it was chosen because of how biotechnology essentially cuts across all standard fields and that its practical implementation requires integration of most disciplines. Future plans for this project call for gathering high school science teachers and university professors together to plan for the integration of the applications of biotechnology into high school science courses during the 1991/92 school year.

A similar move was recently made at Bowling Green State University in Ohio. A semester-long high school course, titled "Bio-related Technology Systems", was developed for the purpose of studying practical applications of biological organisms in making or modifying products, with the expressed intent to provide students with a literacy regarding biologically related technologies (E. Savage, personal communication, April 9, 1990). Most of the materials necessary for the course are of the general technology laboratory variety, with additional materials referenced through science catalogs. The

activities used for this course were garnered from various existing science and technology sources, and were not original in design.

The desire of technology education professionals to include biotechnology within their curricula is further evidenced by the explicit call for biotechnology (bio-related technology) as the "fourth" content organizer, put forth in the document titled "A Conceptual Framework for Technology Education" (Savage and Sterry, 1990). Produced through a grant awarded by the Technical Foundation of America, this manuscript sought to give an overview of technology and the processes associated with doing technology. Within this document a strong case is made for including some aspects of biotechnology in the Technology Curriculum. That case can be summarized in the following points:

1. Biotechnology within Technology courses requires an integrated approach involving a wide range of skills, processes and concepts drawn from across the curriculum. It encourages the development of real inter-departmental cooperation in schools and offers a wide range of motivating design tasks.
2. Biotechnology should appeal to all students but more importantly should act as a catalyst in changing the perception of girls towards technology, drawing as it does from the life sciences.

3. Biotechnology presents both real and relevant human problems to which students can relate. Every student of every cultural background will have some knowledge of traditional biotechnology on which to build an awareness and capability of the new technology.
4. Biotechnology solves human problems in ways that range from the sometimes low-tech processes of food production and waste management, to the hi-tech processes of genetic engineering and fermentation technology. The potential exists for real progression of skills, concepts and awareness throughout the age range from primary through to higher education.
5. The involvement of biotechnology in technology and other courses, is important in order to foster and sustain an awareness of the advances in key areas of biotechnology which will often have social and ethical implications for our society.

The literature indicates a clear need, expressed in this country and others, for developing secondary biotechnology curriculum. Crucial to that development is a thorough analysis of the content reservoir inherent to this subject. Utilization of taxonometric principles can lead to the formation of that reservoir, and eventually to the structure upon which curricula can be developed.

Curriculum Taxonomies

Formulation of taxonometric principles in education originated back in 1948 from a meeting of college examiners attending the American Psychological Association Convention in Boston. In an effort to find a framework for communication between examiners, the group felt the best way to obtain that framework was through a system of classifying the goals of the educational process (Bloom, 1956). They viewed a taxonomy as a source of constructive assistance in the organization of the structural elements of education, prerequisite to the development of any curriculum. As such, they developed a set of principles upon which a taxonomy can be constructed. Those principles are used in other well established knowledge area taxonomies, and serve as selection criteria for structural elements. Since that time this same approach has been utilized in many fields of education.

In the field of Industrial Arts, those same principles were incorporated in a study to develop a taxonomy of practices of ways that man changes the form of materials in construction (Hauenstein, 1966). The taxonomy derived in Hauenstein's study was developed by grouping various levels of questions concerning construction practices, and then arranging them into a hierarchy based on five classifications of construction practices. In technology education curriculum development, this method was most notably made use of by Paul DeVore beginning in the early 1960s. His work in taxonomies is of significant

importance to technology education, and is paralleled in this study. The taxonometric principles set forth by DeVore (1966) can be summarized as follows:

1. The areas in question are mutually exclusive, with groups or categories established in an hierarchical order.
2. The word or phrase chosen to identify the category delimits the area.
3. Each area has a distinct universal concept that is inherent to the knowledge area itself.
4. There is an internal relationship existing between the knowledge areas.
5. The knowledge areas are universal, in that they are international in scope and not bound by geographic or social boundaries.

To DeVore the purpose of a taxonomy is to determine the totality of a knowledge field, along with the component elements and their interrelationships. In support of that position, Werkmeister points out:

> The nature and function of the 'elements' is determined by the position which the 'elements' occupy in the 'structure,' while the 'structure' is what it is because of the 'elements' which constitute it. That is to say, 'structure' and 'element' occur only in indissoluble fusion. There exists no 'structure' without constituent 'elements', and there exist no 'elements' without functional relations of some sort to a 'structure.' (Werkmeister, 1948)

Utilization of the previously outlined taxonometric principles provides the basis for determining a biotechnology content structure in this study. That structure can be used in classifying only the elements of the biotechnology knowledge area, and does not extend to instructional methodologies. Methods of instruction are largely determined by the nature of the content categorized (Ten Hoor, 1963).

The position of biotechnology, as presented in this study, places it at the same hierarchical level as the currently accepted technology knowledge areas of communication, production and transportation (Figure 1).

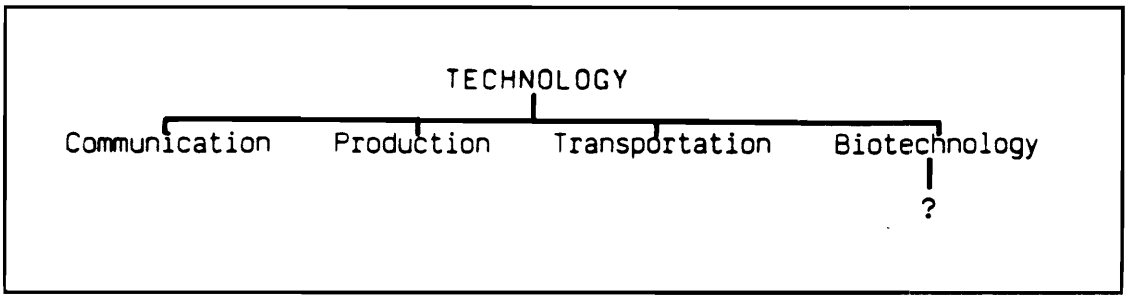

Figure 1

The major divisions of biotechnology at the secondary education level have yet to be determined and agreed upon. Furthermore, the classification of content categories within each of those divisions also requires identification and consensus on their inclusion. This study attempts to fulfill that need making use of established taxonometric principles. To determine that

taxonomy necessitates identification of, and consensus for the major divisions and their subsequent categories, which in this study will be reached through the Delphi technique.

The Delphi Technique: A Method of Prediction

The Delphi technique is a systematic, iterative method for establishing goals, setting priorities, or predicting future events, based on the independent inputs garnered from a group of experts. The fundamental purpose of the technique is to obtain a consensus of opinions from a panel of experts (Weaver, 1971). Delphi is seen as an appropriate initial procedure for determining instructional content, and as in the case of this study, may provide the only available course of action for reaching consensus on certain areas of curriculum content (Finch and Crunkilton, 1979).

Dalkey (1969) refers to the Delphi technique as one based on the premise that 'two heads are better than one' when precise information on an issue is not obtainable (p.408). The Delphi technique is characterized by three features that discriminate it from other methods of group interaction. Those characteristics are summarized as follows:

1. Anonymity. Panel members are not known to each other, and the interaction of the group can thus be handled in a completely anonymous fashion, usually by mailed questionnaires.
2. Iteration with Controlled Feedback. The interaction of the group is conducted through a systematic exercise carried out in a series of iterations, with controlled feedback preventing the group from taking on its own goals and objectives.
3. Statistical Group Response. The Delphi procedure presents a statistical response that includes the entire group. Opinions within a group are taken into account in the median, with the spread being represented by the size of the interquartile range. (Martino, 1975)

Traditional methods of pooling individual opinions through face-to-face discussions, inherently contain some serious pitfalls. According to Dalkey (1972) the following are among the most serious:

1. Influence of dominant individuals. The group opinion can be highly influenced by, for example, the person who talks out the most. There is very little correlation between pressure of speech and knowledge.
2. Noise. By noise is not meant auditory level (although in some face-to-face situations this may be serious enough!) but semantic noise. Much of the communication in a discussion group has to do with individual and group interests, not with problem solving. This kind of

communication, although it may appear problem oriented, is often irrelevant or biasing.

3. Group pressure for conformity. In experiments at RAND and elsewhere, it has turned out that, after face-to-face discussion, more often than not the group response is less accurate than a simple median of individual estimates without discussion.

Of the many strengths attributed to the Delphi method, most important is its ability to avoid the pitfalls of personal interactions, but retain the constructive aspects of group interaction and still move toward a consensus opinion.

The Delphi technique attempts to build a consensus of opinion by asking experts a round of questions, developing more refined questions that are fed back to the respondents, and so on (TLRI, 1991). It seeks controlled elicitation of group opinion, with commentary, by iterative use of questionnaires. The selective feedback from previous group responses is used as an informational basis for ensuing predictions by panel experts of the events, goals, or priorities under consideration.

The classic Delphi calls for four to five rounds to reach consensus (Linestone and Turoff, 1975), though three rounds has been shown to account for virtually all response changes (Martino, 1975; Weatherman and Swenson, 1974). The director of the study synthesizes relevant data from the returned

questionnaires, submitting the statistical results and commentary to the participants as part of the next round. Written comments given by panelists in support of their opinion positions, are fundamental to the process of creating a convergence of group opinions while seeking consensus. Opinions diverging from that of the group are included in the commentaries returned to the panelists. They are, in effect, a non-intrusive persuasion mechanism directed at other panel members (Martino, 1975).

Both statistical and commentary responses are obtained with the Delphi technique, which works to highlight the opinions of the entire group, while still providing equal notice of minority viewpoints. Group response to a given item is usually presented in terms of the median and interquartile range. Data represented in this manner indicates the middle, or average opinion of the group, the spread and the group's central tendency.

The Delphi technique has been the instrument of choice in many education research studies. It has met with success in research specifically conducted by technology education professionals seeking answers to problems in their field (Croft, 1990; Crammer, 1990; Barnes, 1987). The same method has been chosen for this study because the problem under investigation lends itself poorly to other research methodologies.

Summary

The researcher has determined, through review of relative literature, that (1) the influence of science, math and technology has been a major contributor to overall curriculum change in the U.S. educational system over the past thirty years, (2) modern biotechnology is an emerging technology, distinct from traditional or classic biotechnology, having great civic impact both economically and socially, (3) the need for an established knowledge structure for the field of biotechnology exists, and is most efficiently approached using taxonometric principles, and (4) the Delphi Technique is an appropriate initial procedure for gaining information from a panel of experts concerning the determination of the content reservoir of biotechnology.

Movement toward inclusion of biotechnology in secondary education was found to be sparse, though the literature indicates substantial gains occurring over the last few years, both nationally and internationally.

Specifically, in the field of technology education, biotechnology is receiving much attention. There is currently an effort within that profession to embrace this knowledge area as a major content organizer, and to include it as a subject for instruction. To date, however, the literature provides no indication that formative research is being conducted from within the technology education profession for the expressed purpose of ascertaining the basic content reservoir of biotechnology. In light of this, the researcher recognized a

genuine need for investigation into the development of a taxonometric structure that would provide secondary education with a validated biotechnology taxonomy, from which content and curricula can be derived. As modern biotechnology is still in its infancy, perceptions of what it entails are numerous and is still open for debate. Therefore, utilization of the Delphi Technique was viewed as the method of choice for this investigation, as it is well suited to eliciting the opinions of a group of experts and encouraging consensus on issues. The methods and procedures involved in that technique are explained in the following chapter.

CHAPTER III. METHODS AND PROCEDURES

Chapter III addresses the design and implementation of this study. The methodology herein described is the Delphi technique, and was used in pursuit of answers to the following research question:

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

The overall intent of this study was to provide educators with the primary components of a viable biotechnology taxonometric structure. This chapter describes the progression of research methodology utilized in establishing that structure.

Panel Member Sources

Of all aspects to the Delphi method, panel selection would be considered most crucial to the success of the study (Enzer and Brigard, 1970). This process was thus approached in a systematic manner consistent with prior research. Utilizing the review of literature and recommendations obtained during discussions among select doctoral committee members and the

researcher, four sources for experts in, or related to, the field of biotechnology were determined. The sources agreed upon 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. Selection of organizations from within each source was determined by choosing those with the highest standings according to resources such as the Million Dollar Directory, Dunn & Bradstreet, Office of Technology Assessment and U. S. Government Agencies. A list of the source organizations selected for this study is provided in Appendix A.

Panel Member Selection Procedures

Organizations representing each of the four sources were contacted by telephone and asked for a point-of-contact (POC) within the organization from whom recommendations of persons, considered experts with respect to biotechnology, could be obtained. Once identified, the appropriate POC was contacted by phone. A set of criteria for identifying experts was explained to the POC at the outset of the conversation. Those criteria are based on (a) position within the source organization - a generalist was preferred; (b) one or more publications, articles or books, relating to biotechnology; and/or (c) one or more research projects, for scientific or educational purposes, in the field of biotechnology.

Five experts from within each of the four sources were then selected at random from the list of names acquired through the respective source POCs, culminating in a minimum total of 20 potential panel members. All experts were then contacted by mail and asked if they would be willing to serve as a panelist for the study. In the event a prospective panelist declined participation, an alternate was selected at random from the remaining names within the original respective source. Appendix B gives the list of names for those persons who participated as panel members in this study.

Delphi Questionnaires

This study used three instruments that are identifiable as Delphi I, Delphi II and Delphi III. The classic Delphi methodology calls for four to five rounds (Helmer, 1967; Dalkey, 1972; and Linestone and Turoff, 1975), though numerous experiments using short sequences have shown that no advantage results in using more than two rounds. However, 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). Additional support for a three round Delphi was gleaned from a number of more recent studies conducted within the educational field (Combs, 1985; Barnes, 1987; Crammer, 1990; and Croft, 1990).

Development of Delphi I

The instrument used for Delphi I was developed by this researcher as an unstructured, characteristic-retaining variation of the model Delphi approach (see Appendix C, Document B for a copy of the Delphi I instrument). Initiating the study with a delimiting context is a variation on the classic Delphi method, supported through research conducted by Martino (1975). This specific modification 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), have been retained.

The panel members used in this study all have expertise in, or related to, the field of biotechnology. However, considering the institutional diversity of these individuals, the potential exists for their viewpoints to differ drastically, thus resulting in opinions possibly not in line with this study. Of even greater concern is that panel members may not possess knowledge of instructional methodologies at the secondary school level, or understand the intent of biotechnology instruction within a technology education program. Hence there is a need to present a common information base with round one, that provides

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 (see Document A in Appendix C). 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.

Preparation of Delphi I

A package of material containing information necessary for completion of Delphi I was prepared. The package contained the following items: (a) a letter to each member of the panel explaining the purpose of the study, (b) an abstract providing panel members with an initial context reference point from which to view biotechnology instruction, along with a sample taxonometric structure, and (c) the Delphi I instrument, including instructions. This initial document was submitted to both co-chairs for review and critique. Revisions concerning clarity of directions and layout of the Delphi I instrument were made as a result of the review (see Appendix C for a copy of the Delphi I package that was sent to each panel member).

The final Delphi I package contained:

1. An opening letter to the panel members that explained the study.
2. Document A An Introduction and Abstract Describing The Biotechnology Context Used For This Study.
3. Document B Delphi I Answer Form
4. Document C Response To Invitation Form

Administering the Delphi I

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 (no more than eight) representing the ***major*** areas of biotechnology endeavor, and to then denote the subdivisions (categories) 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. A diagram, developed by DeVore (1966) depicting the hierarchical structure of the technology discipline, was included with the Delphi I abstract to graphically demonstrate the developmental intent of this study and the position of biotechnology within the discipline (see Document A in Appendix C).

Research Methodology

The taxonomies received from Delphi I were reviewed by the researcher and two local science experts (designated the "internal committee"), to identify

unique biotechnology knowledge areas. Uniqueness was based on the following set of guiding principles developed by DeVore (1966) to serve as selection criteria for a 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.

Derivation of eight validated biotechnology knowledge areas was approached through an analysis of the titles, and their associated subdivisions, furnished by the experts. Knowledge area titles having identical or extremely similar subdivisions, were grouped together under one of the eight validated knowledge areas. 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 (see Document A in Appendices E and F).

Preparation of Delphi II and III

A package of material necessary for the completion of the Delphi II was prepared. Included in the Delphi II package was (a) a letter to each panel member explaining the second round, (b) the second round research instrument (scale), and (c) a postage-paid envelope for returning the scale

instrument (see Appendix E for a copy of the Delphi II package sent to each panel member). To increase the return rate of the Delphi II, panel members were encouraged to respond via facsimile (FAX). Review and critique by committee members necessitated minor revisions. The resultant final Delphi II package contained the following items:

1. An opening letter explaining the results of Delphi I and procedures for Delphi II.

2. Document A The Delphi II Instrument and Instructions

The Delphi III (Appendix F) packet contained (a) a letter of personal thanks for participating in this study, (b) the third round instrument, (c) a report of the item comment from round two, (d) a "reason" sheet for remaining outside the consensus, and (e) a postage-paid return envelope.

The final Delphi III package contained:

1. A letter of personal thanks and procedures for completing Delphi III.
2. Document A The Delphi III Instrument
3. Document B Report of Delphi II Comments
4. Document C Reason Sheet for Remaining Outside Consensus

Time Line of Events

A time line of research events was constructed (Table 1) to serve as a schedule for the study. The schedule provided target dates for mailing

research materials, obtaining panel responses and for sending out reminder cards to panel members.

Table 1

Time Line January 13, 1992 to June 15, 1992

Identify Panelists	January 13 - 17, 1992
Delphi Developed & Mailed	January 13 - 20, 1992
Reminder Mailed	February 3, 1992
Receipt of Delphi I	March 9, 1992
Delphi I Analyzed	March 10 - 22, 1992
Preparation of Delphi II	March 23 - 31, 1992
Delphi II Mailed	April 3, 1992
Reminder Mailed	April 10, 1992
Receipt of Delphi II	April 27, 1992
Delphi II Analyzed	May 10, 1992
Delphi III Mailed	May 11, 1992
Reminder Mailed	May 18, 1992
Receipt of Delphi III	June 8, 1992
Delphi III Analyzed	June 8 - 15, 1992

Administration of the Delphi Instruments

According to the scheduled date, the Delphi I packet was mailed to all panel members. Each expert was asked to respond to the following research questions: "What are the knowledge areas you feel represent the major areas of biotechnology endeavor?" (limit to eight), and "Under your designated biotechnology knowledge areas, what subdivisions (categories) could each area be broken into as the next sub-level in a structural hierarchy?" (no limit on the number of subdivisions). A copy of the Delphi I instrument is shown in Appendix C.

The panelists were given two weeks in which to respond, with a reminder card sent approximately one week after the initial Delphi I mailing. If a panelist did not respond within a reasonable period of time, they were contacted by phone to ascertain their intentions for participation. The responses were reviewed by the internal committee when all returns were accounted for. In accordance with stated criteria, unique biotechnology knowledge areas, and their associated subdivisions were identified. Preparation of a scale instrument was based on those results (see Document A of Appendix E for a copy of the scaled instrument used).

Following schedule, the Delphi II packet was prepared and mailed to each panelist on the appointed date. A set of instructions accompanied the instrument, detailing the procedures they were to follow in completing the

scaling instrument. The experts were presented with the eight biotechnology knowledge areas that emerged from the structures submitted in the Delphi I, as determined by the internal committee. For each major area, experts were asked to make judgements on the subdivisions (categories) listed below each knowledge area by rating them according to their degree of agreement or disagreement for inclusion in that particular biotechnology knowledge area. Specifically, the higher the rating, the more the panel member indicated the subdivision was critical for thorough instruction in a given knowledge area. Space was 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. The scores assigned by the panelists for each item were entered and saved to a Number Cruncher Statistical System (NCSS) computer file, and a Supercalc (SCALC) spreadsheet file. A report sheet was generated using the NCSS package, giving the 25th, 50th and 75th percentiles, and general descriptive statistics for each subdivision within the eight 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.

The final mailing of the Delphi III occurred according to the date on the time line. Experts were asked to reexamine the scores on the scale report,

with consideration of their position on a given item. They then had the option of adjusting their judgements or leaving them unchanged. Comments obtained from the Delphi II concerning specific subdivisions were included in the round III packet 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, in the self-addressed, stamped envelope provided.

The returned third round rating reports were examined first for accuracy in following instructions. The revised values assigned by the panelists in Delphi III were entered and saved to an NCSS computer file, as well as a SCALC spreadsheet file.

Methods of Analysis

The unique biotechnology knowledge areas identified in Delphi I were used in assembling an instrument, formatted parallel to a Likert-Type scale for the Delphi II.

Likert scaling is a method devised by Rensis Likert for measuring attitudes or judgements concerning psychological traits (Kerlinger, 1973). This method assumes individual items are monotonically related to some underlying trait, and that a summation of item scores approximates a linear relation to the trait. The Likert-type scale developed for this study follows similar reasoning. For this case, the linear relation refers to the item trait, believed by the expert to be inherent with all subdivisions of a given knowledge area. The scores for each item are summed and averaged to yield the group's relative opinion score for that item.

Nunnally (1967) points out that scaling of this manner has advantages over other methods: they (1) follow from an appealing model, (2) are rather easy to construct, (3) usually are highly reliable, (4) can be adapted to the measurement of many different kinds of attitudes, and (5) have produced meaningful results in many studies. As with all attitude scales, the purpose of the summated rating scale is to place an individual somewhere on an agreement continuum for the attitude in question. With respect to this study, the attitude in question will be the degree to which the experts judge an item (subdivision) critical to the instruction of a given biotechnology knowledge area. This means there is no scale of items, per se. One item is the same as any other item in value. It is the individual's responses that are scaled, arrived at by summation and averaging of the total number of responses. By using

the summated rating scale, the intensity of agreement for each item can be found.

A procedure similar to that given by Selltiz, Wrightsman and Cook (1976) was used for constructing the Likert-type scale for this study. Those procedures are as follows: (1) The items designated relevant for inclusion in a given knowledge area were assembled. (2) These items are administered to the group of experts. They indicate their attitude or value response to each item by selecting an intensity value, using an 11 point scale, for inclusion of the item in that specific knowledge area. (3) The item responses are scored in such a way that a response indicative of the most favorable attitude toward inclusion is given the highest score. An 11 point scale was used in this study, with 11 being highest and 1 lowest. (4) Total item scores were determined by summing individual responses to that item and calculating the mean, median and mode for each. (5) The responses are analyzed to determine group consensus concerning item inclusion in a particular biotechnology knowledge area.

Eight knowledge areas were determined from the taxonomy structures returned by panel members in Delphi I, using group consensus of the internal committee. The subdivisions supplied by each respondent for the eight knowledge areas were combined to create eight item (subdivision) lists. In Delphi II the panelists were requested to rate the subdivisions designated in

each of the eight knowledge area lists. The combination of these ratings required the completion of eight scales per panel member. The panelists were instructed to fully complete one scale before beginning the next. It was also made clear that changing responses during the completion of a scale was acceptable, and even encouraged.

Using the rated response value assigned to each item by an individual, Q-values and median scores were computed. Q-values, indicating the interquartile range, were computed for use as an indication of agreement among panel members on a given item. Small Q-values show less dispersion among scores, and are therefore indicative of a greater amount of agreement. In addition, a frequency distribution, using all median scores, was constructed to locate the 25th percentile. The 25th percentile was used to determine the cut-off point of acceptance for inclusion of a subdivision within one of the main knowledge areas.

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 its inclusion within a specific knowledge area. Those categories with calculated Q-values equal to or lower than four indicated strong agreement among experts concerning its 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 bearing high importance to begin with. It follows 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.

Summary

The identification of biotechnology knowledge areas and their corresponding first level subdivisions required the research described in this chapter. Presented in Chapter III was the research design chosen for this identification and the procedures used to carry it out. Specifically, the procedures called for (a) the assemblage of experts in, or related to, the biotechnology field, (b) an instrument to assess their opinions on the issue and (c) a method to statistically analyze those results.

An unstructured, characteristic-retaining variation of the classic Delphi technique was chosen as the most appropriate research method for this study.

This Delphi was used to collect opinions from experts in the field of biotechnology. It was felt that the diversity among experts, combined with the possible lack of understanding with regards to the application of these results at the secondary level, required utilizing this variate of the Delphi. Hence, a brief description concerning the nature of the study was included with the first round to provide a common context from which the experts could initially view the issue.

Following this preface, the Delphi I instrument was then directed at ascertaining opinions on (a) what knowledge areas describe biotechnology, and (b) what subdivisions comprise each of those areas. Delphi II and Delphi III asked the panelists to rate, using a scale instrument similar in format to a Likert-type scale, the major knowledge areas and subdivisions identified in Delphi I.

Using a Likert-type scale, opinions garnered from panelists were rated. This format gave experts an eleven point range in which to rate their judgement on each division, with a score of 1 representing the lowest degree of intensity towards inclusion, and a score of 11 being the highest. Instructions provided in Delphi II and Delphi III specified how the instruments were to be completed. Median scores and Q-values were used in analyzing the data. Q-values, the difference between the 25th and 75th percentiles, determined the level of agreement among panelists, and provided a dispersion

estimate of the judgements. Using this method the level of consensus or diversity among the experts, on opinions toward inclusion of an item to a given knowledge area, was reached.

A frequency distribution of all median scores was constructed to determine the 25th percentile score. This score was used as the cut-off point for determining acceptance of a subdivision as important for thorough instruction of biotechnology.

This chapter described the steps taken in conducting the study. Chapter IV will address the analysis of the data, followed by conclusions and findings in Chapter V.

CHAPTER IV RESEARCH FINDINGS

Presented in this chapter are the research findings for Delphi I, II, and III, along with the calculations used to identify subdivisions considered necessary to the instruction of biotechnology at the secondary school level. The findings for Delphi I include Delphi Respondent data, the response data received from the Returned Delphi I Responses, showing determination of the main biotechnology knowledge areas and their corresponding subdivisions. The research findings received from Delphi II include the data from the Returned Delphi II Responses, the Delphi II Ratings of Subdivision, and comments by panelists to justify their subdivision ratings. Included in the findings from Delphi III are the data from the Returned Delphi III Responses, and Delphi III Ratings of Subdivisions. Findings for the comparative analysis Delphi II and III are also included in this chapter. The chapter concludes with a summary.

Delphi Respondents

Twenty individuals, requested to participate as members of a panel of biotechnology experts, expressed their willingness to take part in this research. Identification of participants was accomplished through a search of four sources heavily involved with various aspects of biotechnology. From each of the four sources (major biotechnology companies; educational organizations

associated with science and technology; government agencies associated with science and technology; universities with major biotechnology programs) 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. Table 2 gives a breakdown of the sources and the number of potential panelists from each of the four.

Table 2

Summary of Source Potential Participants

Source	Title	No. Potential Participants
Educational Organizations	National Association of Biology Teachers	
	National Science Teacher's Association	
	International Technology Education Association	
	American Association for the Advancement of Science	Potentials = 63
Government Agencies	National Aeronautics & Space Administration	
	National Science Foundation	
	Office of Technology Assessment	

(table continues)

Source	Title		No. Potential Participants
Government Agencies (cont'd)	United States Department of Agriculture		
			Potentials = 13
Biotechnology Companies	Monsanto		
	Cyanotech		
	Edvotek		
	Agrigentics		
	Pfizer		
	Photodyne		
	Agracetus		
	Foresight		
	Biomedical Research Center		
	Interdisciplinary Center for Biotechnology Research		
	North Carolina Biotechnology Center		
			Potentials = 25
Universities	San Francisco State Univ	CA	
	Univ. of California	CA	
	Colorado College	CO	
	Regis University	CO	
	Georgetown Univ. Med Cntr	DC	
	Univ. of Florida	FL	
	Valdosta State College	GA	
	Iowa State University	IA	
	Northwestern Univ. Med Sch	IL	
	University of Chicago	IL	
	Ball State University	IN	
	Kansas State University	KS	
	Boston University	MA	

(table continues)

Source	Title	No. Potential Participants
	Cntr. for Marine Biotech.	MD
	University of Maryland	MD
	Southwest Missouri State U	MO
	University of Missouri	MO
	East Carolina University	NC
	N.C. A&T State University	NC
	Univ. of North Carolina	NC
	Central Community College	NE
	Cornell University	NY
	University of Rochester	NY
	Lehigh University	PA
	Texas A&M University	TX
	University of Washington	WA
	Lakeland College	WI
	Madison Area Tech College	WI
	Northeast WI Tech College	WI
	University of Wisconsin	WI
		Potentials = 50
		Total = 151

The twenty individuals randomly selected from each source for inclusion in the initial group of possible panel members were contacted by phone and requested to participate. Of the first five individuals contacted from biotechnology company sources, only two agreed to participate. A second random selection was therefore made from the remaining pool of potential biotechnology company panelists, for three more individuals to contact. All three contacts in this second round of calls agreed to participate. Phone calls

to the first five randomly selected potential panelists from educational organizations resulted in participation agreements by all five contacts. Telephone requests to the first five potential panelists from within government agencies resulted in agreements by only two individuals. Two more random selections were required before an additional three potential panelists agreed to participate. From university sources, the first five individuals contacted all agreed to be panel members and take part in the study. The resultant 20 member panel of biotechnology experts was evenly split between 10 males and 10 females. This split was a purely random occurance. A copy of the final list of panel members used in this study can be found in Appendix B.

Delphi I packages were mailed to the twenty individuals willing to participate in the study. Contained within the packages were (a) a letter to each member of the panel explaining the purpose of the study, (b) an abstract providing panel members with an initial context reference point from which to view biotechnology instruction, along with a sample taxonometric structure, and (c) the Delphi I instrument, which included instructions. From this package of material, panel members were asked to return only the completed Delphi I instrument to the researcher (see Appendix C for a copy of the contents of the Delphi I package).

Two weeks following the mailing out of the Delphi I, reminder letters were mailed to those panel members not yet responding (a copy of the reminder

letter can be found in Appendix D). The intent of this follow-up letter was two fold: (a) to confirm receipt of the Delphi I package, and (b) to give a gentle reminder to the panelists about returning the completed instrument. Those panel members not responding five weeks after the initial Delphi I mailing were contacted by telephone. Table 3 gives details on the types of follow-up methods used in round one.

Table 3
Summary of Follow-up Communications For Delphi I

Expert Source	Letters	Telephone
Educational Organizations	3	1
Biotechnology Companies	4	2
Universities	4	1
Government Agencies	1	0
Total Group	12	4

The first round, Delphi I, concluded seven weeks after the initial mailing. Of the 20 round one panel members agreeing to participate in this research, 19 returned a fully completed Delphi I instrument, while 1 member returned a partially completed instrument (see Document C for a copy of the Delphi I instrument). This constitutes an average response of 95% over the entire

group of respondents. The partially completed instrument came from the government agencies source, resulting in the lowest response (80%) of the four sources. The highest response (100%) was received from experts in the other three sources, where all panel members returned completed instruments. Table 4 shows the responses from each of the four expert sources from Delphi I.

Table 4
Response Rate from Each Source

Group	Number Sent	Number Received	Percent Received
Educational Organizations	5	5	100
Biotechnology Companies	5	5	100
Universities	5	5	100
Government Agencies	5	4	80
Total Group	20	19	95

An explanation for the partial response from the one individual in a government agency was included with the returned instrument. This individual indicated the directions for completing the Delphi I were difficult to follow, with an overabundance of educational jargon, and that they would be of greater help in the second round.

The literature indicates the 95% response of Delphi I to be exceptionally high. First round responses from a number of research studies (Copeland, 1977; Combs, 1985; Barnes, 1987; Croft, 1990) using the Delphi Technique were all found to be lower than 95%. For instance, Barnes' (1987) International Study of Curricular Organizers for the Study of Technology received a first round response of 74% from the total number of expert panel members agreeing to take part in his study. Of the three other studies cited above, the lowest response (54%) was obtained in Croft's study, while the highest (90%) was from the research conducted by Copeland. First round response for the Delphi study done by Combs was 89%. Hence, the response of 95% this researcher received from the first round of 20 panel members, exceeds all of the Delphi research studies cited above.

The size of the panel of experts determined to be acceptable for this study was twenty (N = 20). From the review of literature, it was found that the number of experts used in a Delphi study varied greatly. The range in size of expert panels used in the studies cited above verifies this. The smallest panel of experts used in any of the four studies cited earlier was sixteen (N = 16), while the largest was eighty-one (N = 81). In addition, research conducted by Norman Dalkey (1972) into the experimental study of group opinion, provides further support for the use of small panel sizes. His research findings concerning the dependency of group size to the accuracy of a group response

indicated that less than .5% average group error would result from groups with as few as 16 members. Thus, the group size of twenty (N = 20) chosen by this researcher was deemed acceptable in this study.

Returned Delphi I Responses

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, limiting their response to eight titles. The researcher used a presentation software package to graphically display the main titles submitted by panel members. The panel member names were categorized according to which of the four sources they represented. Columns were used to include those titles of similar characteristics. 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. Table 5 contains a summary of the number of titles submitted by the five members in each of the four expert sources. The panelist source with the highest number of titles (35) being submitted from all five of its members, was that of educational organizations. The lowest number of titles (26) came from those respondents from government agencies.

Table 5

Number of Main Knowledge Area Titles Per Source

	Educational Organizations	Biotech Companies	Universities	Government Agencies
8 Titles	1	2	1	1
7 Titles	3	1	0	1
6 Titles	1	1	3	0
5 Titles	0	0	0	1
4 Titles	0	1	1	1
2 Titles	0	0	0	1
Total Titles	35	33	30	26

Grouping of main knowledge areas was also accomplished 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. Document A in Appendix G lists the main knowledge area titles submitted by panelists, arranged according to the expert source with which they are associated.

Using the method described in the previous paragraph, eight main biotechnology knowledge areas were derived. Those eight knowledge areas, validated by the internal committee, are as follows: (1) Foundations of Biotechnology, (2) Bioprocessing, (3) Bioethics, (4) Genetic Engineering, (5) Agriculture, (6) Biochemistry, (7) Medicine, and (8) Environment.

The second question asked of the panel of experts was to determine subdivisions for each of the main knowledge areas they designated. There was no limit to the number of subdivisions they might break an area into. The total number submitted from the panel of experts, including repeats, equaled 715 subdivisions. Of those 715 submitted, 269 were repeats, leaving 446 as completely unique subdivisions.

With the eight main knowledge areas in place, subdivisions were grouped together according to the main knowledge areas with which they were most closely associated. Many of the subdivisions submitted were clearly at the level of instructional content, and could not be considered a subdivision. They were more appropriately considered content categories for a third level in the taxonometric structure for biotechnology being sought in this study. Although they are not specifically germane to the questions asked of the panelists, it is important that these content categories accompany the results of the study, as they were used in the alignment of subdivisions within a main knowledge area. The entire list of main knowledge areas, their subdivisions as validated by the

internal committee, and the additional categories of instructional content are provided in Document B of Appendix G.

At the completion of the Delphi I, eight main biotechnology knowledge areas were gleaned from the expert responses. Through an analysis conducted by the researcher, in conjunction with the internal committee, subdivisions were aligned within the eight knowledge areas. This final array of verified knowledge areas and subdivisions was used to develop the framework for the Delphi II rating instrument (a copy of the Delphi II instrument can be found in Appendix E). Table 6 presents the final list of main knowledge areas and their subdivisions actually used in the Delphi II instrument.

Table 6

Final List of Main Knowledge Areas & Subdivisions

Main Knowledge Area	Subdivisions
Bioprocessing	1. Fermentation 2. Culturing 3. Microbial Applications 4. Historical Overview 5. Microbial Structure 6. Bio-Products 7. Types of Microorganisms 8. Bioreactor Design 9. Separation & Purification Techniques

(table continues)

Main Knowledge Area	Subdivisions
Bioprocessing (cont'd.)	10. Processing Design: Monitoring & Growth 11. Bioelectronics & Bioworks 12. Processing Types 13. Biomass Conversions 14. Bioprocessing of Fossil Fuels 15. Genetic Engineering 16. Packaging 17. Social Impact
Foundations of Biotechnology	1. Career Information 2. Career Preparation 3. Profiles of Biotechnology Companies 4. Relevant Terms 5. Definition of Biotechnology 6. Historical Background 7. Laboratory Safety 8. Scientific Method 9. Specifications on Lab Journals and Logs 10. Social Impact
Genetic Engineering	1. History & Ethics 2. Probing Techniques 3. Analysis of DNA 4. Basic Research 5. Genetic Code 6. Vector Systems

(table continues)

Main Knowledge Area	Subdivisions
Genetic Engineering (cont'd)	7. Basic Structure of Genetic Material 8. Basic Cell Structures 9. Genome Projects 10. Molecular Bio Techniques 11. Genetic Engineering Applications 12. Marine Biotechnology 13. Social Impact
Agriculture	1. Tissue Culturing 2. Plant Physiological Systems 3. Animal Physiological Systems 4. Aquaculture 5. Food Science 6. Food Safety 7. Social Impact 8. Plant & Animal Genetic Engineering 9. Microbial Applications 10. Plant & Animal Applications 11. Agrichemicals 12. Food Packaging
Biochemistry	1. Proteins 2. Enzymology 3. Methods of Analysis 4. Macromolecular Structure 5. Lipids 6. Carbohydrates 7. Control and Regulation 8. The Genetic Material 9. Social Impact

(table continues)

Main Knowledge Area	Subdivisions
Medicine	
	1. Genetic Therapeutics
	2. Molecular Medicine
	3. Health Care Technologies
	4. Medical Devices
	5. Immunology
	6. Social Impact
Environment	
	1. Biotreatment Systems
	2. Bioremediation
	3. Biological Controls
	4. Biorestoration
	5. Wildlife Management
	6. Safety
	7. Social Impact
Bioethics	
	1. Principles of Ethics
	2. Patenting of Life
	3. Timetable for Development
	4. Impacts of Using Biotechnology
	5. Potentials of Gene Therapy
	6. Population Studies
	7. Forensics
	8. Technology Transfer
	9. Regulation: Legislation & Safety
	10. Social Impact

Returned Delphi II Responses

Approximately two months following the initiation of Delphi I, the 20 panel members were sent Delphi II packages. To expedite the delivery of these

packages, facsimile (FAX) transmission was used with those panel members with access to this method of communication. Of the 20 experts taking part in this study, 17 received the Delphi II package via FAX, while the remaining 3 received it by regular mail. The Delphi II materials contained within these packages were (a) a letter to the panel member explaining the procedures of the second round, and (b) Document A, the Delphi II research instrument, including instructions for its completion. From these materials, panel members were requested to complete and return to the researcher only the Delphi II instrument. The option of returning the instrument by mail or FAX was left to the discretion of the panel member. A total of 15 responses (75%) were returned by facsimile transmission within a one week period of time. This response method appeared to convey a greater sense of urgency to the panelist for returning a completed instrument, resulting in a rapid response rate. An additional two weeks was needed for receipt of the other five responses returned by regular mail. Telephone calls to three of the panel members responding by mail were necessary as a reminder to complete the Delphi II instrument.

The researcher found that completion of the Delphi II round required less time and proceeded in a much smoother manner. The entire second round mailing for this Delphi study, from the point at which the packages were sent out, to receipt of the final response, required 24 days to complete. In addition,

far fewer follow-up contacts were needed in order to get all members to respond. This response time was approximately half that necessary for Delphi I.

All 20 panel members from the Delphi I were sent the Delphi II package. From this total of 20 experts, 19 returned the Delphi II instrument (Document A). One expert source group thus showed an 80% response for the second round. Furthermore, of the 19 responses received, one was not useable, and the individual suggested they be dropped from the study. The suggestion was heeded, bringing the total size for the panel of experts to 18 members. Though the receipt of the instrument has been herein noted, it was viewed and recorded as a "non-receipt", thus producing a second expert source group with an 80% response for the second round. As previously cited from the literature, panels consisting of as few as 18 participants represent a viable panel size for conducting a Delphi study. Table 7 reveals the final Delphi II response rate distribution for each of the expert sources.

Table 7

Delphi II Response Rate from Panel Members

Group	Number Sent	Number Received	Percent Received
Educational Organizations	5	4	80
Biotechnology Companies	5	5	100
Universities	5	5	100
Government Agencies	5	4	80
Total Group	20	18	90

A review of literature revealed that a total response of 90% is well within acceptable limits for second round response rates in Delphi studies. Round two response rates from previous educationally related Delphi studies showed similar levels. Croft (1990) received a second round response of 84% for his research on determining the characteristics of technological literacy for high school students. Other such research efforts by Copeland (1977), Haque (1983) Combs (1985), and Barnes (1987), also noted second round response of similar levels. Respectively those levels were 97%, 75%, 100%, and 96%. In comparison to these similar Delphi studies concerning educational research, a 90% response falls within an acceptable range.

Delphi II Ratings of Subdivisions

Eighty-four subdivisions, distributed among eight main knowledge areas, were rated by the panel of 18 biotechnology experts. Responses were all returned on Document A, the Delphi II instrument (a copy of the Delphi II instrument can be found in Appendix E). Three responses were returned by regular mail, while the remaining fifteen were received through FAX transmission.

A computer spreadsheet was employed to enter names and corresponding responses from each of the 18 panel members. Panel member names were arranged according to the source group they represented; those sources being educational organizations, biotechnology companies, universities, or government agencies. Columns of the spreadsheet corresponded to specific subdivisions, each grouped separately within their main biotechnology knowledge areas. Ratings by panel members for each of the eighty-four subdivisions were recorded in respective columns. Calculations were made by the researcher for each subdivision within a main knowledge area to determine the mode, median and Q-value (interquartile). All 18 panel member responses (N = 18) were used in rating each of the eighty-four subdivisions.

Modal scores were calculated for future use as indicators to panelists of their position on the rating scale relative to the rest of the group. Median scores were calculated for all eighty-four subdivisions, and 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 on the scale, equal to or greater than 8.5, were considered important. Further analysis of the Delphi II data was made to determine the degree of consensus on a given subdivision. Calculated Q-values equal to, or less than 4, represented an acceptable level for consensus.

Table 8 contains a summary of Delphi II responses, listing the subdivisions by main knowledge area and rank ordered according to median scores. Before each subdivision is a number that reflects their rank position. Following each subdivision are the mode (Mo), median (Mdn) and Q-value (Q) responses from the total Delphi panel.

Table 8

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

(table continues)

Rank	Knowledge Area	Subdivision	Mo	Mdn	Q
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

(table continues)

Rank	Knowledge Area	Subdivision	Mo	Mdn	Q
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
7		Career Information	9 11	8.5	4.0

(table continues)

Rank	Knowledge Area	Subdivision	Mo	Mdn	Q
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 to 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 Bio Techniques	11	10.0	2.0

(table continues)

Rank	Knowledge Area	Subdivision	Mo	Mdn	Q
7		Basic Structure of Genetic Material	11	10.0	2.0
8		Genetic Engineering Applications	11	10.0	2.0
9		History & Ethics	11	10.0	2.0
10		Basic Research	11	9.5	4.0
11		Basic Cell Structures	11	9.0	4.0
12		Genome Projects	10	9.0	4.0
13		Marine Biotechnology	7 to 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

(table continues)

Rank	Knowledge Area	Subdivision	Mo	Mdn	Q
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

(table continues)

Rank	Knowledge Area	Subdivision	Mo	Mdn	Q
5		The Genetic Material	10 11*	10.0	2.0
6		Macromolecular Structure	11	9.5	3.0
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

(table continues)

Rank	Knowledge Area	Subdivision	Mo	Mdn	Q
	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

(table continues)

Rank	Knowledge Area	Subdivision	Mo	Mdn	Q
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.

The data gathered from the Delphi II instrument 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 below the median cut-off point of 8.5. As discussed in Chapter III, this median cut-off point was calculated using a frequency distribution of all median scores to determine the 25th percentile score. The main knowledge area of Bioprocessing contained the greatest number of subdivisions (6) below the cut-off point, with all but one showing Q-values of 4.0 or less. All other main

knowledge areas, with the exception of Biochemistry, had at least one subdivision whose median score was below the 8.5 cut-off point. In all but one instance, the calculated Q-value was 4.0 or less. Table 9 gives a summary of those subdivisions from the second round that could tentatively be excluded from the final taxonometric structure.

Table 9

Summary of Delphi II Subdivisions Below the Median Cut-Off

Knowledge Area	Subdivision	Median	Q-value
Bioprocessing			
	Biomass Conversion	8.0	2.0
	Bioprocessing of Fossil Fuels	8.0	2.0
	Processing Types	8.0	2.0
	Bioreactor Design	7.5	3.0
	Historical Overview	7.0	3.0
	Bioelectronics & Bioworks	6.5	3.5
	Packaging	5.5	4.5*
Genetic Engineering	Marine Biotechnology	8.0	3.0

(table continues)

Knowledge Area	Subdivision	Median	Q-value
Foundations in Biotechnology			
	Specifications on Lab Journals and Logs	8.0	3.0
	Career Preparation	7.5	4.0
	Profiles of Biotechnology Companies	6.0	3.0
Agriculture			
	Food Science	8.0	3.0
	Food Packaging	7.0	3.0
Medicine			
	Medical Devices	8.0	3.0
Environment			
	Wildlife Management	8.0	5.0*
Bioethics			
	Population Studies	8.0	2.0
	Timetable for Development	6.5	4.0

* Subdivisions below both median and Q-value cut-offs.

A total of sixteen subdivisions, from seven of the eight main knowledge areas, were rated below the cut-off point for median scores. Two of those sixteen subdivisions also fell outside the acceptable consensus level of 4.0.

Results from the Delphi III round served to verify the degree of consensus thus far found in the second round data.

Delphi II Panel Member Comments

Fundamental to the Delphi Technique is the inclusion of comments from panel members regarding their opinion positions. Written comments by panelists in support of their positions, are central to the process of bringing about convergence of group opinions while seeking consensus. Divergent opinions are included in the commentaries returned to the panelists as a non-intrusive mechanism of persuasion, directed at other panel members.

In Delphi II panelists were requested to give comment on any rating they felt required justification. Space was provided immediately following the rating scale of each subdivision on the Delphi II instrument, as a place for panel members to express their opinions. Appendix H lists the comments and respective ratings submitted by the entire panel of experts for subdivisions in each of the eight main biotechnology knowledge areas.

These comments, along with ratings for the subdivision in question, accompanied the Delphi III instrument. In this way persuasive argument is interjected, and works to highlight the opinions of the entire group, while still providing equal notice of minority viewpoints. The comments list was included

with the Delphi III, and panel members were instructed to refer to them while they completed the third round instrument.

Returned Delphi III Responses

Roughly four months after initiation of this Delphi study, the eighteen panel members were sent Delphi III packages. All Delphi III packages went by regular mail.

Contained within these Delphi III packages were the following: (a) a letter of personal thanks, and procedures for completing the Delphi III, (b) Document A The Delphi III instrument, with instructions, (c) Document B Report of Delphi II Comments, and (d) Document C Reason Sheet for Remaining Outside Consensus, printed on the reverse side of Document A. Panel members were requested to complete and return to the researcher Document A The Delphi III instrument, and Document C Reason Sheet for Remaining Outside Consensus.

Follow-up communication was handled strictly by telephone for the third round. Twelve panel members returned Document A in slightly more than two weeks from the initial mail out, without requiring further contact by the researcher. The remaining six panelists were contacted by telephone to ascertain (a) actual receipt of the Delphi III package, and to (b) remind them of completing and returning the materials.

As with the other two rounds, panelists had the option of returning their responses by regular mail or facsimile transmission. Thirteen of the eighteen panel members replied by mail, four by facsimile transmission, and one orally by telephone. From a total of 18 Delphi III panel members, all eighteen returned the Delphi III instrument (Document A), resulting in a 100% response. The response from each panel member source group is given in Table 10.

Table 10

Delphi III Response Rate from Panel Members

Group	Number Sent	Number Received	Percent Received
Educational Organizations	4	4	100
Biotechnology Companies	5	5	100
Universities	5	5	100
Government Agencies	4	4	100
Total Group	18	18	100

Delphi III Ratings of Subdivisions

The 84 subdivisions, rated once already in the second round, were again distributed to the 18 biotechnology experts for reappraisal in the Delphi III. All

responses were returned on Documents A and C of Appendix F. This scale was a modification of the second round instrument, with an additional component 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. The modal position for each subdivision was circled on the Delphi III instrument as an indication of majority. Panel members were to use this point as a reference for where their opinions fell with regards to the rest of the group.

A spreadsheet format, identical to that used for Delphi II data, was employed for input of data from Delphi III responses. Specifically, this format placed subdivisions in columns, grouped according to the main knowledge area of which they were a subset. Panel member names were by row, with their subdivision ratings recorded along that row in the appropriate columns. Median and Q-value calculations were made by the researcher for each subdivision within a given main biotechnology knowledge area. All responses from the panel of eighteen experts were used in this round three rating of the eighty-four individual subdivisions.

An analysis of the Delphi III data was performed to determine the degree of consensus for each subdivision. As previously stated, calculated Q-values of 4

or less indicate an acceptable level of consensus by the group for the subdivision in question.

Median scores were determined for all subdivisions, and compared to the previously determined median cut-off score of 8.5. Those subdivisions with median score values at or above this cut-off point were considered important to the construction of a valid taxonmetric structure, and targeted for inclusion in the final biotechnology taxonomy.

With 18 panel members rating subdivisions in eight separate knowledge areas, an analysis was made to determine which of the eight main areas had the greatest percent of its subdivisions with the highest (rating = 11.0) and lowest (rating < 8.5) rated levels of importance. The main knowledge area with the greatest percent of its subdivisions (50%) at the highest level of importance (r = 11.0), was Bioethics. At the opposite extreme, the main knowledge area of Bioprocessing had the largest percent of its subdivisions (41%) at the lowest level of importance (r < 8.5). Table 11 summarizes the percent distribution of subdivisions at the upper and lower levels of importance for each main knowledge area.

Table 11

Percent Distribution of Subdivisions at Upper & Lower Levels

Subdivision	% Upper Level (r = 11.0)	% Lower Level (r < 8.5)
Bioethics	50	20
Genetic Engineering	39	8
Biochemistry	33	0
Medicine	33	0
Agriculture	25	8
Foundations In Biotechnology	20	20
Bioprocessing	18	41
Environment	14	14

Table 12 below entails a summary of the total Delphi III response ratings, listing subdivisions by main knowledge area and rank ordered by median scores. Before each subdivision is a number that reflects their rank position. Following each subdivision are the median and Q-value ratings from the total Delphi panel responses. Modal scores were not required for analysis of the third round data, and therefore not calculated.

Table 12

Summary of Delphi III Ratings

Rank	Knowledge Area	Subdivision	Mdn	Q
	Bioprocessing			
2		Fermentation	11.0	1.0
2		Culturing	11.0	1.0
2		Genetic Engineering	11.0	1.0
4.5		Microbial Applications	10.5	1.5
4.5		Social Impact	10.5	3.0
6		Separation & Purification Techniques	10.0	2.0
8.5		Bio-Products	9.0	1.0
8.5		Types of Microorganisms	9.0	1.0
8.5		Microbial Structure	9.0	1.0
8.5		Processing Design: Monitoring & Growth	9.0	2.0
12		Biomass Conversions	8.0	1.0

(table continues)

Rank	Knowledge Area	Subdivision	Mdn	Q
12		Bioprocessing of Fossil Fuels	8.0	0.0
12		Processing Types	8.0	1.0
14		Bioreactor Design	7.5	2.0
15		Historical Overview	7.0	2.0
16		Bioelectronics & Bioworks	6.0	2.0
17		Packaging	5.5	3.5
	Foundations in Biotechnology			
1.5		Laboratory Safety	11.0	1.0
1.5		Social Impact	11.0	2.0
3		Scientific Method	10.0	2.0
4		Definition of Biotechnology	9.5	3.0
5		Historical Background	9.0	3.0

(table continues)

Rank	Knowledge Area	Subdivision	Mdn	Q
7		Relevant Terms	8.5	2.0
7		Career Information	8.5	3.0
7		Specifications on Lab Journals and Logs	8.5	1.0
9		Career Preparation	8.0	2.0
10		Profiles of Biotechnology Companies	6.0	2.0
	Genetic Engineering			
3		Genetic Code	11.0	1.0
3		Social Impact	11.0	2.0
3		Analysis of DNA	11.0	1.0
3		Genetic Engineering Applications	11.0	2.0
3		History & Ethics	11.0	2.0
6.5		Basic Structure of Genetic Material	10.5	2.0

(table continues)

Rank	Knowledge Area	Subdivision	Mdn	Q
6.5		Basic Cell Structures	10.5	2.0
10		Vector Systems	10.0	1.0
10		Probing Techniques	10.0	2.0
10		Molecular Bio Techniques	10.0	2.0
10		Basic Research	10.0	2.0
10		Genome Projects	10.0	2.0
13		Marine Biotechnology	8.0	2.0
	Agriculture			
2		Tissue Culturing	11.0	1.0
2		Plant & Animal Genetic Engineering	11.0	1.0
2		Social Impact	11.0	1.0
5.5		Microbial Applications	10.0	1.0

(table continues)

Rank	Knowledge Area	Subdivision	Mdn	Q
5.5		Plant & Animal Applications	10.0	1.0
5.5		Animal Physiological Systems	10.0	2.0
5.5		Plant Physiological Systems	10.0	2.0
9.5		Agrichemicals	9.0	2.0
9.5		Food Safety	9.0	2.0
9.5		Aquaculture	9.0	2.0
9.5		Food Science	9.0	2.0
12		Food Packaging	7.0	4.0
	Biochemistry			
2		Proteins	11.0	1.0
2		Social Impact	11.0	3.0
2		Control and Regulation	11.0	2.0
4		Macromolecular Structure	10.5	2.0
6		Enzymology	10.0	1.0

(table continues)

Rank	Knowledge Area	Subdivision	Mdn	Q
6		Methods of Analysis	10.0	2.0
6		The Genetic Material	10.0	2.0
8.5		Carbohydrates	9.0	3.0
8.5		Lipids	9.0	2.0
	Medicine			
1.5		Social Impact	11.0	1.0
1.5		Molecular Medicine	11.0	1.0
3		Immunology	10.5	1.0
4.5		Genetic Therapeutics	10.0	1.0
4.5		Health Care Technologies	10.0	2.0
6		Medical Devices	8.0	2.0
	Environment			
1		Social Impact	11.0	1.0
2		Biotreatment Systems	10.5	2.0

(table continues)

Rank	Knowledge Area	Subdivision	Mdn	Q
4.5		Biological Controls	10.0	1.0
4.5		Bioremediation	10.0	1.0
4.5		Biorestoration	10.0	1.0
4.5		Safety	10.0	2.0
7		Wildlife Management	8.0	4.0
	Bioethics			
3		Social Impacts	11.0	0.0
3		Principles of Ethics	11.0	2.0
3		Impacts of Using Biotechnology	11.0	2.0
3		Regulation: Legislation & Safety	11.0	2.0
3		Potentials of Gene Therapy	11.0	1.0
6		Patenting of Life	10.0	2.0
7.5		Forensics	9.0	2.0

(table continues)

Rank	Knowledge Area	Subdivision	Mdn	Q
7.5		Technology Transfer	9.0	2.0
9		Population Studies	8.0	2.0
10		Timetable for Development	7.0	2.0

Analysis Delphi III Subdivision Ratings

An analysis was conducted on the data received from the Delphi III respondents. The results of the Delphi III were examined by separate main biotechnology knowledge areas and in their entirety. As with the Delphi II data, the 25th percentile of all median scores, previously determined by a frequency distribution of total scores, was used to locate the cut-off point for the minimum acceptable level of importance. That median score cut-off point was 8.5.

The seventeen subdivisions rated in the Bioprocessing knowledge area showed median score values ranging from 11.0 to 5.5. Ten of those subdivisions showed median score values above the cut-off point, signifying that 59% were within the acceptable range with regard to level of importance. Q-values for all seventeen subdivisions ranged from 0.0 to 3.5, indicating

general agreement by the panel on the ratings given. The Bioprocessing knowledge area contained the lowest percentage of subdivisions at or above the 8.5 median cut-off point.

The knowledge areas of Biochemistry and Medicine both had 100% of their subdivisions within the acceptable range for level of importance. In addition, Q-values ranged from 1.0 to 3.0, and 1.0 to 2.0 respectively for Biochemistry and Medicine. Strong agreement concerning the high level of importance for these subdivisions, in both main knowledge areas, is evident from the low Q-values.

Genetic Engineering and Agriculture showed 92% of their subdivisions falling within the range of acceptability for level of importance. The range of Q-values for Genetic Engineering was 1.0 to 2.0, and for Agriculture was 1.0 to 4.0, indicating group concordance on subdivision ratings.

Response data for the main biotechnology knowledge area of Environment revealed 86% of its subdivisions were well above the 8.5 median cut-off point. Six of the seven subdivisions received a rating of 10.0 or higher. Strong consensus for the ratings given these subdivisions was evident from the Q-values, which ranged only from 1.0 to 2.0 for the six within the acceptable level of importance.

Bioethics and Foundations In Biotechnology both had 80% of their subdivisions at or above the 8.5 median cut-off point. Q-scores for either

knowledge area were no greater than 3.0, pointing to high agreement among panel members for the ratings given those subdivisions.

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. Table 13 gives a summary of the relative standings for the eight main knowledge areas, ranked by the percent subdivision ratings at, or above the median cut-off score of 8.5, and average median scores.

Table 13

Percent Subdivisions Above Median Cut-Off Score & Avg. Mdn

Main Knowledge Area	Rank by Subdivision (% Above Median Cut-off)	Avg. Mdn (total)
Biochemistry	100	10.17
Medicine	100	10.08
Genetic Engineering	92	10.31

(table continues)

Main Knowledge Area	Rank by Subdivision (% Above Median Cut-off)	Avg. Mdn (total)
Agriculture	92	9.67
Environment	86	9.93
Bioethics	80	9.80
Foundations in Biotechnology	80	9.00
Bioprocessing	59	8.82

Delphi II & III Movement Toward Consensus

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 greater consensus on the degree of importance for nearly every subdivision. In all instances, this movement was toward a higher rating. For example, the main knowledge area Biochemistry had nine subdivisions rated in Delphi II in the following manner: one rated 10.5, Q = 2.0; four rated 10.0, Q = 2.0, 2.0, 2.0, 3.0; two rated 9.5, Q = 3.0, 5.0; one rated 9.0, Q = 2.0; and one rated 8.5, Q = 2.0. Data from Delphi III showed seven of the nine ratings increased, with a general decrease in all Q-values. The new ratings from Delphi III are as follows: three rated 11.0, Q = 1.0, 3.0, 2.0; one rated 10.5, Q = 2.0; three rated 10.0, Q = 1.0, 2.0, 2.0; zero rated at 9.5, and two rated at 9.0, Q = 3.0, 2.0. This represents a shift of 76% of the nine subdivisions to a higher rating, with an accompanying increase in general consensus about these subdivisions at their newer level of importance. The Biochemistry knowledge area showed the most marked shift of all eight areas. However, the general trend to shift subdivisions upward in the level of importance was consistent across all main knowledge areas. Table 14 below summarizes this trend to shift subdivisions upward along the scale of importance, and also the general strengthening of consensus revealed in the downward shift of Q-values.

Table 14

Summary of Trend Toward Higher Ratings from Delphi II to III

Knowledge Area	Ratings	Subdiv/Rating D-II	Subdiv/Rating D-III	Mean Q-Value D-II	Mean Q-Value D-III	% Shift
Biochemistry						
	11.0	0	3	3.2	2.0	76
	10.5	1	1			
	10.0	4	3			
	9.5	2	0			
	9.0	1	2			
	8.5	1	0			
	<8.5	0	0			
Medicine						
	11.0	1	2	1.83	1.33	67
	10.5	0	1			
	10.0	3	2			
	9.5	0	0			
	9.0	1	0			
	8.5	0	1			
	<8.5	1	0			
Agriculture						
	11.0	0	3	2.25	1.75	67
	10.5	1	0			
	10.0	4	4			
	9.5	1	0			
	9.0	2	4			
	8.5	2	0			
	<8.5	2	1			

(table continues)

Knowledge Ratings Area	Subdiv/Rating D-II	D-III	Mean Q-Value D-II	D-III	% Shift
Genetic Engineering					
11.0	2	5	2.23	1.77	62
10.5	0	2			
10.0	7	5			
9.5	1	0			
9.0	2	0			
8.5	0	0			
<8.5	1	1			
Bioethics					
11.0	1	5	2.3	1.70	60
10.5	0	0			
10.0	4	1			
9.5	1	0			
9.0	1	2			
8.5	1	0			
<8.5	2	2			
Bioprocessing					
11.0	0	3	2.59	1.53	41
10.5	1	2			
10.0	4	1			
9.5	0	0			
9.0	4	4			
8.5	1	0			
<8.5	7	7			

(table continues)

Knowledge Ratings Area	Subdiv/Rating D-II	D-III	Mean Q-Value D-II	D-III	% Shift
Foundations in Biotechnology					
11.0	1	2	3.3	2.1	40
10.5	0	0			
10.0	2	1			
9.5	0	1			
9.0	1	1			
8.5	3	3			
<8.5	3	2			
Environment					
11.0	1	1	2.29	1.71	14
10.5	0	1			
10.0	5	4			
9.5	0	0			
9.0	0	0			
8.5	0	0			
<8.5	1	1			

Mean Q-values in each of the 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 $\underline{Q}(avg) = 2.45$, with a standard deviation of 1.17. In comparison, the overall mean Q-value for the Delphi III data set was $\underline{Q}(avg) = 1.74$, with a standard deviation of .58.

The above calculations, and those given in Table 14, 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 following list (Table 15) of main biotechnology knowledge areas and their respective subdivisions is the result of a comparative data analysis between Delphi II and III. These are the subdivisions observed by the researcher which were rated above the median cut-off score of 8.5 by the panel of experts, and having Q-values of 4.0 or less.

Table 15

Final List of Biotechnology Knowledge Areas & Subdivisions

Biotechnology Knowledge Area	Subdivisions
Bioprocessing	
	1. Fermentation
	2. Culturing
	3. Genetic Engineering
	4. Microbial Applications
	5. Social Impact
	6. Separation & Purification Techniques
	7. Bio-Products
	8. Types of Microorganisms
	9. Microbial Structure
	10. Processing Design: Monitoring/Growth

(table continues)

Biotechnology Knowledge Area	Subdivisions
Foundations in Biotechnology	1. Laboratory Safety 2. Social Impact 3. Scientific Method 4. Definition of Biotechnology 5. Historical Background 6. Relevant Terms 7. Career Information 8. Specifications on Lab Journals and Logs
Genetic Engineering	1. Genetic Code 2. Social Impact 3. Analysis of DNA 4. Genetic Engineering Application 5. History & Ethics 6. Basic Structure of Genetic 7. Basic Cell Structures 8. Vector Systems Material 9. Probing Techniques 10. Molecular Bio Techniques 11. Basic Research 12. Genome Projects
Agriculture	1. Tissue Culturing 2. Plant & Animal Genetic Engineering 3. Social Impact 4. Microbial Applications 5. Plant & Animal Applications

(table continues)

Biotechnology Knowledge Area		Subdivisions
Agriculture (cont'd)	6.	Animal Physiological Systems
	7.	Plant Physiological Systems
	8.	Agrichemicals
	9.	Food Safety
	10.	Aquaculture
	11.	Food Science
Biochemistry		
	1.	Proteins
	2.	Social Impact
	3.	Control and Regulation
	4.	Macromolecular Structure
	5.	Enzymology
	6.	Methods of Analysis
	7.	The Genetic Material
	8.	Carbohydrates
	9.	Lipids
Medicine		
	1.	Social Impact
	2.	Molecular Medicine
	3.	Immunology
	4.	Genetic Therapeutics
	5.	Health Care Technologies
Environment		
	1.	Social Impact
	2.	Biotreatment Systems
	3.	Biological Controls
	4.	Bioremediation
	5.	Biorestoration
	6.	Safety

(table continues)

Biotechnology Knowledge Area	Subdivisions
Bioethics	
	1. Social Impacts
	2. Principles of Ethics
	3. Impacts of Using Biotechnology
	4. Regulation: Legislation & Safety
	5. Potentials of Gene Therapy
	6. Patenting of Life
	7. Forensics
	8. Technology Transfer

The list of main biotechnology knowledge areas and their subdivisions presented above have been 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. Of the eighty-four subdivisions originally presented to the panel for rating fifteen were excluded, leaving sixty-nine to comprise the final list. In Table 12, all subdivisions with median scores below 8.5 were withdrawn from the final list. Q-values for those fifteen subdivisions were no greater than 4.0, indicating consensus by panel members on their scale ratings.

Table 16 presents a summary of the subdivisions excluded from the final list.

Table 16

Summary of Delphi III Subdivisions Below the Median Cut-Off

Knowledge Area	Subdivision	Median	Q-value
Bioprocessing			
	Biomass Conversion	8.0	1.0
	Bioprocessing of Fossil Fuels	8.0	0.0
	Processing Types	7.5	2.0
	Bioreactor Design	7.5	2.0
	Historical Overview	7.0	2.0
	Bioelectronics & Bioworks	6.0	2.0
	Packaging	5.5	3.5
Genetic Engineering	Marine Biotechnology	8.0	2.0
Foundations in Biotechnology			
	Career Preparation	8.0	2.0
	Profiles of Biotechnology Companies	6.0	2.0

(table continues)

Knowledge Area	Subdivision	Median	Q-value
Agriculture			
	Food Packaging	7.0	4.0
Medicine			
	Medical Devices	8.0	2.0
Environment			
	Wildlife Management	8.0	4.0
Bioethics			
	Population Studies	8.0	2.0
	Timetable for Development	7.0	2.0

The data resulting from the Delphi III indicated that agreement could be achieved by panel members on the primary components of a biotechnology taxonometric structure. Specifically, consensus was reached on a set of viable subdivisions arranged within eight main biotechnology knowledge areas. The analysis revealed that sixty-nine subdivisions comprised those necessary for instruction of biotechnology at the secondary school level. Conclusions centered around this analysis are found in Chapter V.

Summary

The research methodology employed in this study consisted of a three round Delphi technique. An appropriate modification, a delimiting context

preface, was necessary for ensuring the correct initial approach to the study by the select panel members. The identification of main biotechnology knowledge areas and their respective subdivisions was accomplished using a group of experts consisting of individuals from educational organizations, biotechnology companies, universities and government agencies.

Delphi I was used to first identify eight main biotechnology knowledge areas as the primary level of the taxonometric structure. Delphi I also sought to distinguish those subdivisions each of the eight main knowledge areas should be divided into. Through Delphi I, the experts identified eight main biotechnology knowledge areas, and a total of 715 subdivisions distributed among them. Of the 715 subdivisions submitted, a list of 446 unique items was compiled. Through an analysis of this resultant list eighty-four distinct subdivisions were identified.

In Delphi II, the second round, the list of eight main knowledge areas, along with their 84 subdivisions, was sent to the panel of experts for rating. Panel members rated the subdivisions according to the level of importance they associated with the subdivision, using an eleven point scale to numerically designate that level. Responses from each panel member were analyzed to calculate the median and interquartile range values for each subdivision. Subdivisions with median scores greater than 8.5, the 25th percentile cut-off score, were considered at an acceptable level of importance for inclusion in

the biotechnology taxonomy. A Q-value of 4.0 or less was also necessary for consensus of the calculated level of importance.

In Delphi III a similar process of rating was again performed on the 84 subdivisions. However, in this round respondents had feedback comments from Delphi II. This third round found that 82% of the subdivisions rated were within the acceptable consensus and level of importance range. The remaining 18% of the subdivisions did not receive acceptable rating levels, with consensus from the panel for the lower ratings clearly evident for each.

Comparisons between Delphi II and III showed strong movement toward consensus on subdivision ratings. Based on the results and comparisons of Delphi II and III, confirmation of the research question posed in this study was obtained.

The results of the research have been reported in Chapter IV. Contained in Chapter V is a summary of the procedures utilized in this study, conclusions, and recommendations for future efforts to determine an appropriate taxonometric structure for biotechnology at the secondary school level.

CHAPTER V

CONCLUSIONS and RECOMMENDATIONS

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. Before such inclusion can take place, a structure from which biotechnology content can be derived and made deliverable within secondary school education must be developed.

This study was designed to address the problem, currently faced by general high school education, of the abscence of an agreed upon structure for incoporating biotechnology instruction at the secondary school level.

The research was conducted in an effort to reach consensus by a panel of experts on primary components of such a structure, as might be included in a technology education or biological science program.

The specific research objective of the study asks, to what degree can a consensus be reached, through a panel of experts, in determining the primary components of a biotechnology taxonometric structure for the secondary school level? The purpose of this study was therefore to determine a method that would provide educators with a viable taxonometric structure for the development of biotechnology curriculum. Specifically, such a taxonomy, derived through expert consensus, would allow for future development of secondary biotechnology curriculum, applicable within both a technology education program or biological sciences program.

Restatement of Methods and Procedures

The Delphi technique was the methodology selected as most appropriate for the pursuit of the stated research objective. The Delphi panel of experts consisted of diverse individuals representing educational organzations, biotechnology companies, universities and government organizations. Panelists were asked to generate up to eight main biotechnology knowledge areas and the appropriate subdivisions within each. The subdivisions, presented to the panel on an eleven-point scale, were rated according to level

of importance, then returned and analyzed for median and interquartile values. A total of three Delphi rounds were used to reach an acceptable consensus.

Biotechnology experts were selected from four sources recognized for their involvement in biotechnology research and education. These sources were established through a review of literature and recommendations made by committee co-chairs. Twenty experts were randomly selected from a potential pool of 151 individuals.

Panel members participating in this study were identified and selected from the following four sources:

1. Educational Organizations
2. Biotechnology Companies
3. Universities
4. Government Organizations

From each of these four sources, five individuals meeting established criteria for experts in the field of biotechnology, were randomly selected. These twenty specialists comprised the Delphi panel of experts.

The main biotechnology knowledge areas and their subdivisions were derived from an analysis of the original titles submitted in the Delphi I by the total panel of experts. Both the knowledge areas and subdivisions were verified by the researcher and members of an internal committee.

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. A total of 446 unique subdivision titles were submitted by the panelists, from which a list of 84 primary titles was derived. The main knowledge area and subdivision titles were used to construct the Delphi II instrument.

For Delphi II, panel members were requested to rate the subdivisions, using an eleven point scale, with regard to the level of importance for their inclusion in the final taxonometric structure. Slightly more than three weeks were needed for the return of all responses.

Eighteen panel members (90%) returned fully completed Delphi II instruments. Calculations were made to determine the mode (Mo), median (Mdn), and interquartile (Q) values for each subdivision. One panel member dropped out of the study and another response was not useable.

In the third and final round, members of the Delphi panel were asked to re-rate the importance of the subdivisions previously presented in Delphi II. Comments generated from round two were included with the Delphi III materials for review by panelists as a non-intrusive mechanism of persuasion. Approximately one month was necessary for all Delphi III responses to be returned.

Eighteen Delphi III panel members returned the completed third round instrument, a 100% response. Median and interquartile values for each subdivision were again determined from the total group response.

In Delphi II, 20% of the total number of subdivisions were rated below the acceptable level of importance for inclusion in this developing biotechnology taxonomy. Round three showed a decrease in the percentage of subdivisions (17%) falling below the acceptable level of importance. An overall movement toward higher ratings of subdivisions within all eight main knowledge areas was observed, with upward shifts ranging from 14% to 76% (Table 14). In addition, Q-values in each of the eight knowledge areas decreased from Delphi II to Delphi III, indicating convergence of opinions.

Cummulative analysis of data from rounds two and three provides additional evidence for converging opinions. Overall mean Q-values for Delphi II and III were $\underline{Q}$(avg) = 2.45 and $\underline{Q}$(avg) = 1.74 respectively, demonstrating a strong general movement toward consensus for subdivision ratings. Furthermore, overall standard deviations in Q-values between each round (Delphi II: SD = 1.17, Delphi III: SD = .58) give added verification of panel members reaching consensus on subdivision ratings.

Conclusions

The conclusions drawn from this research are based on the information contained in the data received from the Delphi technique, used to address the research objective defined for this study. Conclusions are directed at the primary components of a taxonometric structure for biotechnology. They are presented under two headings: (1) Main Biotechnology Knowledge Areas and (2) Main Knowledge Area Subdivisions, and are followed by justification based on the data received.

Main Biotechnology Knowledge Areas

- Conclusion I

  A panel of diverse members, representing experts in the field of biotechnology, could reach agreement on the main knowledge areas in biotechnology appropriate for students at the secondary school level.

Eight titles (Table 17) were found necessary to adequately address the main knowledge areas for the field of biotechnology. The data received in the first round of the Delphi procedure revealed a wide variety of titles, which initially appeared to be only slightly related. On closer inspection the 124 titles submitted by the panel of experts had similarities that clearly related to specific biotechnology knowledge areas.

An analysis of these titles showed they could be grouped based on (a) the title itself and/or (b) the subdivisions listed beneath the title. This analysis, conducted by the researcher and an internal committee of science experts, determined there were a total of eight distinct categories addressed by the panel members. Agreement was reached among members of the internal committee on the specific wording each knowledge area title would contain. The outcome of this analysis resulted in the list of main knowledge areas shown in Table 17. It was therefore concluded that these eight main biotechnology knowledge areas effectively encompassed the subject matter of biotechnology, and constituted the first level in a taxonometric structure for the instruction of biotechnology at the high school level.

Table 17
Main Biotechnology Knowledge Areas

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

Main Knowledge Area Subdivisions

- Conclusion II

  A panel of diverse members, representing experts in the field of biotechnology, could reach agreement on the appropriate subdivisions within the eight main biotechnology knowledge areas.

- Conclusion III

  The field of biotechnology lends itself to an hierarchical taxonometric classification scheme.

Sixty-nine subdivisions (refer to Table 15) reached concensus of opinion relative to the acceptable level of importance for inclusion in the biotechnology taxonomy. These subdivisions were distributed among the eight main knowledge areas at varying levels of importance as rated on an eleven point scale. It was evident from these results that some subdivisions were perceived to be of greater importance than others. Table 11 summarizes the percentage of subdivisions receiving the highest rating (r = 11.0) in each of the main knowledge areas. 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.

Specifically, 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. Refer to Table 11 for a list of the subdivisions receiving top ratings.

The implication of this data is 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 percent 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.

Data from Delphi II and Delphi III indicated strong movement toward consensus among panel members. Mean subdivision Q-values, representing the average interquartile range, dropped consistently in every main knowledge area. The average drop in Q-value for all eight knowledge areas was .76, slightly more than three quarters of a point. This is a large reduction in the

individual interquartile ranges, and demonstrates increased certainty by panel members of their ratings, whether low or high.

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%). Four of the six had greater than 80% of their subdivisions rated at the high end; the two outstanding ones being Agriculture and Bioethics with 58% and 60% respectively. Table 13 shows this data, along with the average median subdivision score for each main knowledge area. Comparisons between the "percent subdivisions above the median cut-off score" and "average median scores" show fairly consistent rankings of main knowledge areas with regard to the importance given to their subdivisions.

It can be concluded that the subdivisions in the main knowledge areas indicated above, 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 futher 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 85% and 83% of their subdivision, respectively, rated at the high end. The two main knowledge areas with the lowest percentage of subdivisions at the high end, 35% and 30%, were Bioprocessing and Foundations In Biotechnology. Agreement among panel members on highly rating the subdivisions in these main knowledge areas was not nearly as strong as in the other six. The inference from this information is that panel members feel only a small number of the subdivisions submitted for Bioprocessing and Foundations In Biotechnology accurately address the categories of greatest importance.

- Conclusion IV

  Panel members felt the topic of "Social Impact" was necessary for inclusion in any curriculum developed for instruction of biotechnology at the secondary school level.

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 including instruction on the current and potential

impacts biotechnology can have on society is clearly evident among the panel members.

Implications

The eight main biotechnology knowledge areas and their accompanying subdivisions, identified in this study by experts in the field of biotechnology, may be used by educators in technology education or biological sciences. 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 15 presents the final list of knowledge areas, with their corresponding subdivisions rank ordered by median scores. The use of this list by educators in technology education or biological sciences is likely differ in the approach to curriculum development and delivery of instructional content within the classroom setting.

For instance, in Bioprocessing 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

alcohol. Their efforts might then be directed at the system as a whole, designing it to address a specific need. An example can be found in the beer industry, where a solution was needed for efficiently separating out yeast cells from the desired end product. To do so would increase the efficiency and reduce costs.

Understanding the environmental and biological requirements yeast cells have for fermentation to proceed, a method of cell immobilization in gelatinous beads could be used. Imbedded within the porous beads, yeast cells could still act on the sugar solution while remaining separate from the it. This is the utilization of a biotechnical process as a component of a larger system.

In contrast, the approach taken by instructors of biological sciences might have students focus more on the mechanisms of oxidation that are involved with the variety of known fermentation processes. Students would perhaps 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.

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 be 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 biotechnical knowledge in one course, and its application in the other.

Recommendations for Further Research

The results of this research suggest several plausible studies related to the establishment of a taxonometric structure for the study of biotechnology. The following recommendations are therefore offered for consideration in future research.

1. Replication of this research is recommended to obtain confirmation of these findings concerning identification of (a) the main biotechnology knowledge areas, and (b) the main knowledge area subdivisions.

2. As modern biotechnology is an emerging technology, replication of this research is recommended to investigate the evolution of the field of biotechnology over time, and to up-date the knowledge areas and subdivisions.

3. If a replication of this research is conducted, it is recommended that a larger panel of experts be used to avoid the problems of attrition encountered in this study.

4. As this research established only the first two levels of a biotechnology taxonomy, continued efforts should be directed at establishing (1) content categories, (2) basic concepts and principles of the content categories, (3) units of content instruction, and (4) the courses of study based on grouping of logical combinations of instructional units.

5. Additional research should be conducted to develop an interdisciplinary model for parallel biotechnology courses in technology education and biological science.

6. Additional research should be conducted to design activities for biotechnology courses delivered in the technology education program, that are problem-solving in nature, requiring the application of the biotechnology knowledge base established in this study.

7. It is recommended that this research be extended to include biotechnology experts from other countries to gain an international perspective of what is appropriate biotechnology instruction at the high school level.

8. Additional research should be conducted to determine the requirements needed to prepare current instructors in both technology education and biological sciences for implementation of a biotechnology course within their curriculum.

9. Additional research should be conducted to ascertain what university level courses would be required for technology education majors in preparation for instruction of biotechnology content at the high school level.

10. Future studies should be conducted to determine the instructional facility requirements necessary to effectively deliver biotechnology instruction at the high school level. The studies should concentrate on laboratory design and equipment that would allow for students' progression from basic information gathering to actual prototyping.

11. A recognized inadequacy was apparent from an examination of the data. Additional research should be directed at addressing the overlap of some subdivisions, which is inconsistent with stated taxonometric principals.

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APPENDIX A

LIST OF SOURCE ORGANIZATIONS

SELECTED FOR THIS STUDY

List of Source Organizations Selected for this Study

Educational Organizations

1. National Association of Biology Teachers
2. National Science Teacher's Association
3. International Technology Education Association
4. American Association for the Advancement of Science

Government Agencies

1. National Aeronautics & Space Administration
2. National Science Foundation
3. Office of Technology Assessment
4. United States Department of Agriculture

Biotechnology Companies

1. Monsanto
2. Fotodyne
3. Biomedical Research Center
4. Interdisciplinary Center for Biotechnology Research
5. North Carolina Biotechnology Center

Universities

1. Regis University, Colorado
2. University of Florida, Florida
3. Valdosta State College, Georgia
4. University of Wisconsin, Wisconsin

APPENDIX B

NAMES OF PANEL MEMBERS

Names of Panel Members

Educational Organizations

- Dr. Mary L. Bellamy
  National Association of Biology Teachers
  Reston, Virginia

- Mr. Paul Devine
  Glascow High School
  Newark, Delaware

- Dr. Toby Horn
  Biotechnology Laboratory Instructor
  Alexandria, Virginia

- Mr. Leo Palmero
  North Rockland High School
  Thielis, New York

Biotechnology Companies

- Mr. Gary Barton
  Monsanto Agricultural Company
  St. Louis, Missouri

- Dr. Kathleen Kennedy
  North Carolina Biotechnology Center
  Research Triangle Park, North Carolina

- Dr. Barbara Sina
  Biomedical Research Center
  Rockwell, Maryland

- Mr. Brian Walsh
  Fotodyne, Inc.
  New Berlin, Wisconsin

- Ms. Gail Zavelson
  ICBR Biotechnology
  Gainesville, Florida

Universities

- Dr. Deborah Blake
  Regis University
  Denver, Colorado

- Dr. Dennis Bogyo
  Valdosta State College
  Valdosta, Georgia

- Dr. Rosalina Hairston
  University of SO Mississippi
  Hattiesburg, Mississippi

- Dr. Michael Patrick
  University of Wisconsin
  Madison, Wisconsin

- Ms. Lori Van Boening
  Central Community College
  Hastings, Nebraska

Government Agencies

- Dr. Thomas Jeffries
  U.S. Department of Agriculture
  Madison, Wisconsin

- Dr. Daniel Jones
  U.S. Department of Agriculture
  Washington, District of Columbia

- Dr. Robert D. Lumsden
  Beltsville Agriculture Research Center, West
  Beltsville, Maryland

- Dr. Barbara Lujan
  National Aeronautics & Space Administration
  Washington, District of Columbia

APPENDIX C

DELPHI I PACKAGE

Opening Letter to Panel Members

VIRGINIA TECH
Virginia Polytechnic Institute & State University

Technology Education
144 Smyth Hall, Blacksburg, VA 24061-0432
Phone: (703) 231-6480 Fax: (703) 231-4188

Dear

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. The move toward an increased understanding of the technical applications of life processes needs to be approached from the standpoint of the new technologies and biological systems used to that end. In order for curricula and instructional programs in biotechnology to be developed, initial agreement on the knowledge structure must be ascertained. The present study is thus directed at establishing that taxonometric structure, from which a general, introductory high school biotechnology curriculum would then be developed.

As an individual recognized for expertise in the biotechnology field, you have been recommended to me by Dr. David Micklos, Director of the DNA Learning Center, for participation in this Delphi study, which aims to determine a taxonometric structure for biotechnology instruction.

A Delphi study is a systematic, iterative method for establishing goals, setting priorities, or predicting future events, based on independent inputs garnered from a group of experts. The fundamental purpose of such a study is to obtain a consensus of opinions from of a panel of individuals knowledgeable about the questions of interest. In order to obtain opinions from a cross section of notable persons working at the leading edge of biotechnology education, it is very important that your input be included. This research is to be conducted in three phases.

Phase 1. The initial phase is a Delphi instrument (enclosed in this envelope) requesting responses to two open-ended questions. Responses are returned to the researcher in a postage paid envelope, or FAXed (the number is on the instrument).

Phase 2. The second phase instrument will be mailed no later than March 9, 1992. This will consist of a compilation of the major knowledge areas and subdivisions submitted by panel members in the first round. You will be asked to rate these with respect to the appropriateness of their inclusion in a given knowledge area. The rating sheets are returned in a postage paid envelope, or FAXed.

VIRGINIA TECH
Virginia Polytechnic Institute & State University

Technology Education
144 Smyth Hall, Blacksburg, VA 24061-0432
Phone: (703) 231-6480 Fax: (703) 231-4188

Phase 3. The third phase instrument will be mailed no later than March 9, 1992. You will receive the same list of knowledge areas and subdivisions rated in round two. For each subdivision a median and Q value will be given, indicating the level of consensus for every item. You will be requested to rate the items once again and return them via a postage paid envelope.

In each phase the time required to complete an instrument should be approximately 30 minutes. Since panel members never meet, anonymity and confidentiality are maintained, permitting an open forum with equal representation by all.

The results of this study will be made available upon receipt of the request form included in round three. The information obtained through this research will provide the foundation for future development of a general high school biotechnology curriculum.

If you choose to participate, please read the instructions, complete the enclosed questionnaire, and return it in the postage paid envelope. Should you be unable to take part in this important study, please indicate so on the enclosed information sheet and return it as soon as possible.

We would be more than happy to answer any questions you may have regarding this study, and may be reached at the following telephone and/or FAX numbers: 703-231-6480 / 703-552-0642 / FAX 703-231-4188.

Your experience and expertise are important factors in determining the significance of this research. I sincerely hope you will accept this invitation to participate. Thank you for your assistance.

Respectfully,

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Blacksburg, VA
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James E. LaPorte
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241 Lane Hall
Virginia Tech
Blacksburg, VA
24061

DOCUMENT A

An Introduction and Abstract Describing

The Biotechnology Content Used For This Study

DELPHI I

Introduction:

The overall intent of this study is to provide educators with the primary components of a viable biotechnology taxonometric structure. The instrument used for Delphi I was developed as an unstructured, characteristic-retaining variation of the model Delphi approach. This specific modification calls for a preface to the first round instrument, providing panel experts with an initial *context* reference point for the study as an informative measure. The opening abstract provides participants with a common information base by specifying the philosophical and instructional basis for technology education, the targeted level of instruction, the purpose of that instruction, and the environment in which it would take place.

Part I Instructions:

The following is a brief abstract presenting panel members with a common information base. The intent is to provide an initial context reference point from which to view the issue of determining high school biotechnology "content" for a technology education program, based on a taxonometric approach. This approach is graphically presented in the final paragraph of the abstract. Carefully read this material before proceeding to the second part of this instrument.

Abstract

Philosophical and Instructional Basis for Technology Education

Technology is considered a body of knowledge of the technical ways that humans change their environment to satisfy their needs. At present, the most widely accepted definition of technology education requires the study of four technical human-adaptive systems: Communications, Construction, Manufacturing and Transportation. These are the four major "content" areas of technology education. Biotechnology is being considered as the fifth major "content" area, and is the focus of this study.

Technology education curricula are designed to afford a balanced combination of theoretical and practical information with a generous amount of manipulative activities, which are included to insure reinforcement of conceptual understanding. This is a purposeful strategy intended to take advantage of students' inherent interest in discovering, creating, problem-solving and constructing, using tools, machines, materials and processes that are part of the various technology systems. In short, technology education is designed to foster technological literacy for "the general populace."

Purpose and Level of Instruction

The specific, long term goal of technology education is to promote technological literacy as a component of the basic education being provided to all individuals in this country. Such education enables students to function effectively within a technological world.

The biotechnology content being sought in this study is intended for use in future

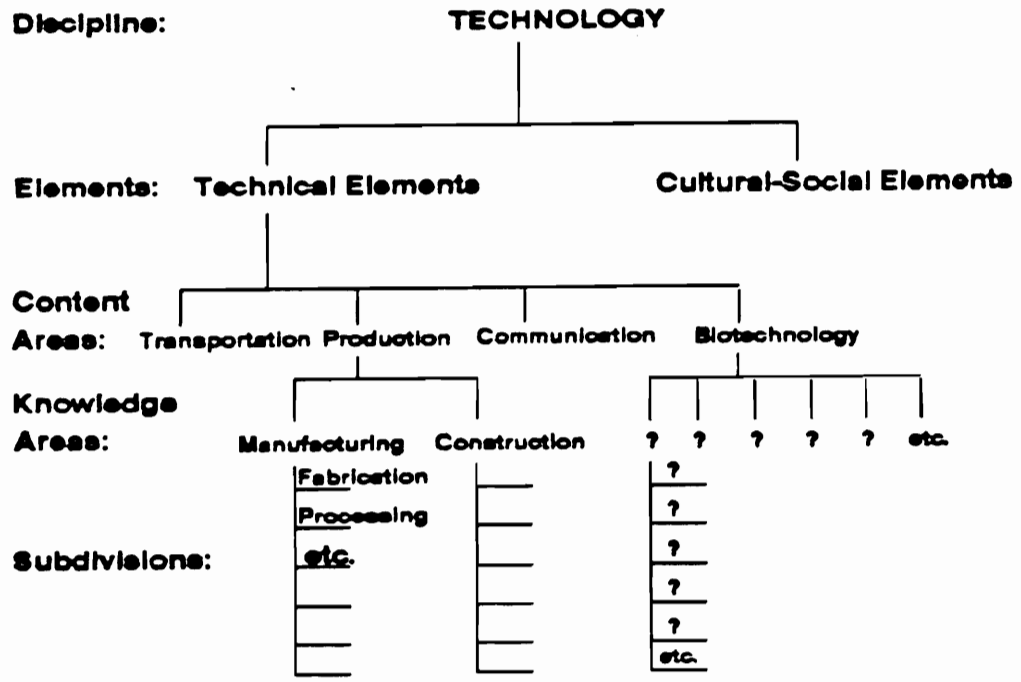
development of instructional curriculum for students at the ***high school*** level. More specifically, it is targeted at the average students in grades nine and ten - the point at which general biology instruction is usually given in high school. The instructional purpose of biotechnology at this grade level, as a component of technology education, is strictly to promote ***general biotechnology literacy***. It is NOT to develop future biotechnologists or lab technicians, though it may result in the development of career interests in these and related occupations.

Instructional Environment

The ideal instructional facility would resemble that of a basic R&D laboratory. Students work at typical lab tables where water, electricity and air are available. Materials are available for the construction of functional prototypes, designed to address and develop solutions to problems requiring biological processes. Such materials would include those needed in the design of electronic circuitry, the growth of microbial cultures, the construction of manufacturing/production/processing systems, and access to computer information and design software.

Taxonometric Structure of the Technology Discipline

The following diagram depicts the hierarchical structure for the technology discipline. It shows the relative position of biotechnology within the taxonomy developed for technology, and gives examples of knowledge areas specific to the other content divisions. This visual aid is provided to more clearly convey to panel members the approach to identifying unique knowledge areas of biotechnology.



* Provides the basis for valid content selection.

DOCUMENT B

Delphi I Answer Form

Part II Questionnaire Instructions:

Based on the biotechnology context provided above, use your knowledge and expertise in the field of biotechnology to answer the following questions. Please submit your responses using the form provided on the next page.

1. What are the knowledge (content) areas you feel represent the MAJOR areas of biotechnology endeavor? (limit to 8)

2. Under your designated biotechnology knowledge areas, what subdivisions (content categories) could each area be broken into as the next level in a structural hierarchy. (no limit on the number of subdivisions; use reverse side for additional space)

MAJOR BIOTECHNOLOGY KNOWLEDGE AREAS:
(max = 8)

1. _____

subdivisions =

_____ _____ _____

_____ _____ _____

_____ _____ _____

2. _____

subdivisions =

_____ _____ _____

_____ _____ _____

_____ _____ _____

3. _____

subdivisions =

_____ _____ _____

_____ _____ _____

_____ _____ _____

4. _____

subdivisions =

_____ _____ _____

_____ _____ _____

_____ _____ _____

5. _____

subdivisions =

_____ _____ _____

_____ _____ _____

_____ _____ _____

6. _____

subdivisions =

_____ _____ _____

_____ _____ _____

_____ _____ _____

7. _____

subdivisions =

_____ _____ _____

_____ _____ _____

_____ _____ _____

8. _____

subdivisions =

_____ _____ _____

_____ _____ _____

_____ _____ _____

John G. Wells
Research Associate
Virginia Tech
334 Lane Hall
Blacksburg, VA 24061

DOCUMENT C

Response To Invitation Form

Memorandum

To: John G. Wells
Research Associate
College of Education
334 Lane Hall
Virginia Tech University
Blacksburg, VA 24061

From: _____

_____

_____

_____

Phone _____

Date: March 02, 1992

Topic: In response to the invitation to serve on a Select Panel of Biotechnology Experts.

_____ Yes, I would be pleased to serve as a member of your Select Panel on determining a taxonometric structure for high school biotechnology, and look forward to receiving the remaining two questionnaires.

_____ I regret that I will not be able to participate in this study as a member of your Select Panel.

Comments: _____

_____

_____

Important:

Please complete and return this memorandum in the postage paid return envelope provided. If you have elected to serve on the panel, include it with your completed Delphi I questionnaire as soon as is convenient for you. You may FAX the response if it is more convenient.

APPENDIX D

REMINDER LETTERS SENT

Dear :

On January 20th you were mailed a letter detailing a biotechnology research project I am conducting at Virginia Tech, which requested your participation as a panel expert. As of this writing I have not received a response from you. You are among a select few I have requested to participate, and your inclusion as a panel member is paramount for the completion of a valid study. I am therefore sending you this reminder to encourage your completion of the questionnaire previously sent, and to return it to me as soon as possible in the stamped self-addressed envelope which was provided.

If you have already completed and mailed the questionnaire, then please disregard this notice. Thank you for your time and assistance with this research.

Sincerely,

John G. Wells

Dear:

On _____ you were mailed a packet containing the materials necessary to complete the Delphi II, round two of the biotechnology research project I am conducting at Virginia Tech. As of this writing I have not received a response from you. You are among a select few I have requested to participate, and your inclusion as a panel member is paramount for the completion of a valid study. I am therefore sending you this reminder to encourage your completion of the questionnaire previously sent, and to return it to me as soon as possible in the stamped self-addressed envelope which was provided.

If you have already completed and mailed the questionnaire, then please disregard this notice. Thank you for your time and assistance with this research.

Sincerely,

John G. Wells

APPENDIX E

DELPHI II PACKAGE

An Opening Letter To Panel Members

VIRGINIA TECH
Virginia Polytechnic Institute & State University

Technology Education
144 Smyth Hall, Blacksburg, VA 24061-0432
Phone: (703) 231-6480 Fax: (703) 231-4188

April 3, 1992

Dear

Thank you for your participation in the Delphi I to identify the main biotechnology knowledge areas and their instructional subcategories. As a panel member, your input represents an important contribution along with other biotechnology experts from universities, government agencies, biotechnology companies and educational organizations associated with science and technology.

At this phase in the research, eight main biotechnology knowledge areas have been identified through your responses to the Delphi I instrument. The breadth of subcategories suggested for each knowledge area indicated a great deal of thought by panel members in their attempts to cover all aspects of biotechnology. Without question the content of the field was thoroughly addressed. Through the efforts of a local committee, topics were grouped under subcategory titles that best represented a content domain within a given biotechnology knowledge area. As a result, not all subcategories submitted by panel members will appear in this second instrument.

Your task in Delphi II will be to make judgements on the subcategories, rating them according to your degree of agreement/disagreement regarding their inclusion in a particular biotechnology knowledge area. You may also give comments in support or opposition to your rating of a subcategory.

After receipt of all responses from the total panel of experts, a third instrument will be sent to you. This instrument will provide the response averages as well as comments by panel members. This phase calls for your further review and presents an opportunity to change your responses.

With 20 experts located across the country, I am attempting to expedite this process by using FAX communication. The majority of panel members have FAX capability and have agreed to complete the study by this method. Regular postal service will be used for those members not having access to FAX. I am requesting that you respond to the Delphi II within five working days. Your immediate reply will ensure the prompt start of the third round of subcategory review by all panel members. **FAX number: (703) 231-4188**

Once again, thank you for your assistance.

Sincerely,

John G. Wells

DOCUMENT A

The Delphi Instrument and Instructions

Instrument #2: Delphi II - Summative Scale

Panel Member Name: _____

The eight biotechnology knowledge areas identified by the panel of experts are listed below. Following each are the subcategories submitted by panel members for inclusion in that particular knowledge area. To the right of each subcategory is a scale ranging from 1 (Not Important) to 11 (Critical). Circle the number within this range that best reflects your opinion concerning the inclusion of that subcategory within the specified knowledge area. If you have a comment concerning any subcategory, write it in the space that follows each of them.

BIOPROCESSING

(Knowledge Area #1)

1. **Fermentation** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

   Comment:

2. **Culturing** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

   Comment:

3. **Microbial Applications** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

   Comment:

4. **Historical Overview** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

   Comment:

5. **Microbial Structure** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

   Comment:

6. **Bio-Products** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

7. **Types of Microorganisms** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

8. **Bioreactor Design** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

9. **Separation and Purification Techniques** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

10. **Processing Design: Monitoring & Growth** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

11. **Bioelectronics and Bioworks** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

12. **Processing Types** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

13. **Biomass Conversions** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

14. **Bioprocessing of Fossil Fuels** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

15. **Genetic Engineering** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

16. **Packaging** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

17. **Social Impact** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

INTRODUCTION TO BIOTECHNOLOGY

(Knowledge Area #2)

1. **Career Information** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

2. **Career Preparation** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

3. **Profiles of Biotechnology Companies** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

4. **Relevant Terms** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

5. **Definition of Biotechnology** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

6. **Historical Background** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

7. **Laboratory Safety** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

8. **Scientific Method** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

9. **Specifications on Lab Journals and Logs** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

10. **Social Impact** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

BIOETHICS

(Knowledge Areas #3)

1. **Principles of Ethics** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

   Comment:

2. **Patenting of Life** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

   Comment:

3. **Timetable for Development** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

   Comment:

4. **Impacts of Using Biotechnology** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

   Comment:

5. **Potentials of Gene Therapy** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

   Comment:

6. **Population Studies** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

   Comment:

7. **Forensics** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

   Comment:

8. **Technology Transfer** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

9. **Regulation: Legislation & Safety** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

10. **Social Impact** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

GENETIC ENGINEERING

(Knowledge Area #4)

1. **History & Ethics** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

2. **Probing Techniques** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

3. **Analysis of DNA** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

4. **Basic Research** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

5. **Genetic Code** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

6. **Vector Systems** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

7. **Basic Structures of Genetic Material** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

8. **Basic Cell Structures** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

9. **Genome Projects** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

10. **Molecular Bio Techniques** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

11. **Genetic Engineering Applications** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

12. **Marine Biotechnology** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

13. **Social Impact** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

AGRICULTURE

(Knowledge Area #5)

1. **Tissue Culturing** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

2. **Plant Physiological Systems** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

3. **Animal Physiological Systems** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

4. **Aquaculture** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

5. **Food Science** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

6. **Food Safety** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

7. **Social Impact** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

8. **Plant & Animal Genetic Engineering** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

9. **Microbial Applications** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

10. **Plant & Animal Applications** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

11. **Agrichemicals** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

12. **Food Packaging** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

BIOCHEMISTRY

(Knowledge Area #6)

1. **Proteins**	*Not Important*	1	2	3	4	5	6	7	8	9	10	11	*Critical*
	Comment:												
2. **Enzymology**	*Not Important*	1	2	3	4	5	6	7	8	9	10	11	*Critical*
	Comment:												
3. **Methods of Analysis**	*Not Important*	1	2	3	4	5	6	7	8	9	10	11	*Critical*
	Comment:												
4. **Macromolecular Structures**	*Not Important*	1	2	3	4	5	6	7	8	9	10	11	*Critical*
	Comment:												
5. **Lipids**	*Not Important*	1	2	3	4	5	6	7	8	9	10	11	*Critical*
	Comment:												
6. **Carbohydrates**	*Not Important*	1	2	3	4	5	6	7	8	9	10	11	*Critical*
	Comment:												
7. **Control and Regulation**	*Not Important*	1	2	3	4	5	6	7	8	9	10	11	*Critical*
	Comment:												

8. **The Genetic Material** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

9. **Social Impact** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

MEDICINE

(Knowledge Area #7)

1. **Genetic Therapeutics** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

2. **Molecular Medicine** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

3. **Health Care Technologies** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

4. **Medical Devices** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

5. **Immunology** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

6. **Social Impact** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

ENVIRONMENT

(Knowledge Area #8)

1. **Biotreatment Systems** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

2. **Bioremediation** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

3. **Biological Controls** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

4. **Biorestoration** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

5. **Wildlife Management** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

6. **Safety** *Not Important* 1 2 3 4 5 6 7 8 9 10 11 *Critical*

Comment:

APPENDIX F

DELPHI III PACKAGE

A Letter of Personal Thanks and Procedures

June 2, 1992

Dear

It is expected that the Delphi III enclosed will be the final instrument you need to complete for my research. When completed and returned, the subcategories will again be analyzed for consensus among the panel of experts. Subcategories agreed upon by panel members for inclusion in a given biotechnology knowledge area will comprise the second hiearchical level in this developing taxonomy.

The Delphi III instrument itself provides panel members with the following information: (1) MODE - the most frequently selected rating for the subcategory in question, (2) RESULTS OF DELPHI II - data showing the frequency of responses (actual number of panel members choosing a specific rating) for a given subcategory, and the rating YOU CHOSE for that item, which is circled.

The last page contains additional information from the second round instrument. Here you are presented with the comments or reasons respondents gave for rating an item. It would be helpful to have these pages out when completing the Delphi III to gain insight about why panel members rated particular subcategories.

For this third instrument, you should consider the group responses along with the reasons given by respondents outside the consensus range (two ratings either side of the mode), and then circle your new rating in the "NEW RESPONSE" column. As you rate each item again, keep in mind you are rating an item according to its importance as a subcategory in a particular knowledge area.

The Delphi technique calls for respondents who do not agree with the majority of the group to indicate his/her reason for remaining outside the consensus. Therefore, if your new response for a particular subcategory is more than two points away from the modal response, you should indicate your reason for selecting that rating score. On the reverse side of each page is space to give comment. The reasons given will play a major role in the results of this study.

I would very much appreciate if you would complete and mail this five page instrument within five working days from the time it is received, in the stamped self-addressed envelope provided.

I cannot express strong enough my gratitude to you for participating in this study. Completion of these instruments took valuable time away from your own personal schedules, which is no small request. Your ideas and opinions have been valuable contributions towards determining a base level structure from which a high school biotechnology curriculum may be developed.
The findings of this research will be sent to you in the near future. If at anytime I may be of assistance to you, please do not hesitate to call on me.

Sincerely,

John G. Wells
Research Associate, VPI&SU

DOCUMENT A

The Delphi III Instrument

Delphi III Instrument

DIRECTIONS: **Panel Member Name:** _____

Subcategories for each biotechnology knowledge area are listed below, followed by the MODAL (most commonly chosen) rating and FREQUENCY DISTRIBUTION (number of people choosing a given rating) of the responses. Your original rating for each item from the previous Delphi instrument is circled under "Results of Delphi II." After considering the responses of the other panel members from the frequency distribution, circle your new rating in the column entitled "New Response." If this new response, whether the same or different from the original, is more than two points from the MODAL rating, please indicate the reason for your position on the back of the page If the new rating is within a two point spread, no reason is necessary. Comments about specific subcategories received from the Round II instrument are provided on separate pages, and are to be viewed as anonymous arguments for or against that subcategory.

EXAMPLE	1	2	3	4	5	6	7	8	9	10	11	(Place "reason" on back of page.)
100. Bioreactor Design	0	0	1	0	3	2	0	11 (Mode)	1	0	2	1 2 (3) 4 5 6 7 8 9 10 11 — New rating more than two points away from MODAL rating. Reason SHOULD be given.
101. Bio-Products	0	1	0	3	13 (Mode)	0	2	1	0	0	0	1 2 (3) 4 5 6 7 8 9 10 11 — New rating two or less points away, or same as MODAL rating. No reason needed.

SUBCATEGORIES	MODE	RESULTS OF DELPHI II (Frequency of Responses) NOT IMPORTANT … CRITICAL											NEW RESPONSE NOT IMPORTANT … CRITICAL										
		1	2	3	4	5	6	7	8	9	10	11											
(BIOPROCESSING)																							
1. Fermentation	Mode =11	0	0	0	0	0	0	2	0	2	(5)	9	1	2	3	4	5	6	7	8	9	10	11
2. Culturing	Mode =10 & 11	0	0	0	0	0	0	2	0	0	(8)	8	1	2	3	4	5	6	7	8	9	10	11
3. Microbial Applications	Mode =11	0	0	0	0	0	0	2	1	3	(4)	6	1	2	3	4	5	6	7	8	9	10	11
4. Historical Overview	Mode =7	1	0	0	0	(2)	2	7	1	3	1	1	1	2	3	4	5	6	7	8	9	10	11
5. Microbial Structure	Mode =9	1	0	2	0	1	(1)	2	1	5	3	1	1	2	3	4	5	6	7	8	9	10	11
6. Bio-Products	Mode =9	0	0	0	0	0	0	1	2	6	(5)	2	1	2	3	4	5	6	7	8	9	10	11
7. Types of Microorganisms	Mode =9	0	0	0	0	0	1	(1)	3	8	3	2	1	2	3	4	5	6	7	8	9	10	11
8. Bioreactor Design	Mode =7	0	1	0	1	1	1	5	2	(1)	3	3	1	2	3	4	5	6	7	8	9	10	11

YOUR response from the Delphi II is circled.

SUBCATEGORIES	MODE	RESULTS OF DELPHI II (Frequency of Responses)											NEW RESPONSE										
		NOT IMPORTANT										CRITICAL	NOT IMPORTANT										CRITICAL
		1	2	3	4	5	6	7	8	9	10	11											
(BIOPROCESSING)																							
9. Separation & Purification Techniques	Mode -11	0	0	0	0	1	0	5	2	(2)	1	7	1	2	3	4	5	6	7	8	9	10	11
10. Processing Design: Monitoring/Growth	Mode -10	0	1	0	1	0	1	4	2	(1)	5	3	1	2	3	4	5	6	7	8	9	10	11
11. Bioelectronics & Bioworks	Mode -5	0	0	2	1	3	2	2	2	(2)	1	1	1	2	3	4	5	6	7	8	9	10	11
12. Processing Types	Mode -8	0	1	0	1	1	1	3	6	1	1	0	1	2	3	4	5	6	7	8	9	10	11
13. Biomass Conversions	Mode -8	0	0	0	0	1	(2)	3	7	4	1	0	1	2	3	4	5	6	7	8	9	10	11
14. Bioprocessing of Fossil Fuels	Mode -8	0	1	1	0	0	2	2	6	2	1	(2)	1	2	3	4	5	6	7	8	9	10	11
15. Genetic Engineering	Mode -11	1	0	0	0	0	0	1	1	2	4	(8)	1	2	3	4	5	6	7	8	9	10	11
16. Packaging	Mode -1,6	4	0	1	1	2	4	(2)	1	1	0	0	1	2	3	4	5	6	7	8	9	10	11
17. Social Impact	Mode -11	1	0	1	1	1	1	0	2	0	3	(8)	1	2	3	4	5	6	7	8	9	10	11
(INTRODUCTION TO BIOTECHNOLOGY)																							
1. Career Information	Mode -9,11	1	1	0	2	0	2	2	1	4	1	(4)	1	2	3	4	5	6	7	8	9	10	11
2. Career Preparation	Mode -8,9	1	1	0	1	(2)	3	1	4	4	0	1	1	2	3	4	5	6	7	8	9	10	11
3. Profiles of Biotechnology Companies	Mode -5-9	0	1	2	2	(3)	3	3	0	3	1	0	1	2	3	4	5	6	7	8	9	10	11
4. Relevant Terms	Mode -9	1	0	0	0	2	2	1	3	4	2	(3)	1	2	3	4	5	6	7	8	9	10	11
5. Definition of Biotechnology	Mode -11	1	0	1	1	0	2	1	2	2	1	(7)	1	2	3	4	5	6	7	8	9	10	11
6. Historical Background	Mode -8,11	0	0	0	1	1	2	1	(4)	2	3	4	1	2	3	4	5	6	7	8	9	10	11
7. Laboratory Safety	Mode -11	1	0	0	0	0	0	0	1	1	(3)	12	1	2	3	4	5	6	7	8	9	10	11
8. Scientific Method	Mode -11	1	0	0	0	1	(2)	1	0	3	3	7	1	2	3	4	5	6	7	8	9	10	11
9. Specifications on Lab Journals & Logs	Mode -8,10	1	0	0	1	(1)	1	2	4	3	4	1	1	2	3	4	5	6	7	8	9	10	11
10. Social Impact	Mode -11	0	0	0	1	0	0	0	2	3	2	(10)	1	2	3	4	5	6	7	8	9	10	11

Your response from the Delphi II is circled.

SUBCATEGORIES	MODE	RESULTS OF DELPHI II (Frequency of Responses) NOT IMPORTANT → CRITICAL											NEW RESPONSE NOT IMPORTANT → CRITICAL										
		1	2	3	4	5	6	7	8	9	10	11	1	2	3	4	5	6	7	8	9	10	11
(GENETIC ENGINEERING)																							
1. History & Ethics	Mode = 11	0	0	0	0	1	1	0	2	3	4	(6)	1	2	3	4	5	6	7	8	9	10	11
2. Probing Techniques	Mode = 10,11	0	0	0	0	0	0	0	2	3	6	(6)	1	2	3	4	5	6	7	8	9	10	11
3. Analysis of DNA	Mode = 11	0	0	0	0	0	0	0	0	4	6	(8)	1	2	3	4	5	6	7	8	9	10	11
4. Basic Research	Mode = 11	0	0	0	0	0	2	4	1	1	3	(5)	1	2	3	4	5	6	7	8	9	10	11
5. Genetic Code	Mode = 11	0	0	0	0	0	0	1	1	1	5	(10)	1	2	3	4	5	6	7	8	9	10	11
6. Vector Systems	Mode = 10,11	0	0	0	0	0	0	1	1	2	7	(7)	1	2	3	4	5	6	7	8	9	10	11
7. Basic Structure of Genetic Material	Mode = 11	0	0	0	0	1	0	0	1	4	5	(7)	1	2	3	4	5	6	7	8	9	10	11
8. Basic Cell Structures	Mode = 11	0	0	0	1	0	1	3	3	2	2	(6)	1	2	3	4	5	6	7	8	9	10	11
9. Genome Projects	Mode = 10	0	0	1	1	0	0	2	1	(5)	8	0	1	2	3	4	5	6	7	8	9	10	11
10. Molecular Bio Techniques	Mode = 11	0	0	0	0	0	0	2	1	3	(4)	7	1	2	3	4	5	6	7	8	9	10	11
11. Genetic Engineering Applications	Mode = 11	0	0	0	0	0	1	1	0	6	2	(8)	1	2	3	4	5	6	7	8	9	10	11
12. Marine Biotechnology	Mode = 7-10	0	0	1	1	1	2	3	(3)	3	3	0	1	2	3	4	5	6	7	8	9	10	11
13. Social Impact	Mode = 11	0	1	0	0	1	0	1	2	1	2	(9)	1	2	3	4	5	6	7	8	9	10	11
(AGRICULTURE)																							
1. Tissue Culturing	Mode = 11	0	0	0	0	0	0	2	0	3	(4)	9	1	2	3	4	5	6	7	8	9	10	11
2. Plant Physiological Systems	Mode = 11	0	0	0	0	1	1	2	2	3	4	(5)	1	2	3	4	5	6	7	8	9	10	11
3. Animal Physiological Systems	Mode = 10	0	0	0	0	1	2	2	(3)	3	4	3	1	2	3	4	5	6	7	8	9	10	11
4. Aquaculture	Mode = 10	0	0	0	1	1	1	3	3	2	4	(3)	1	2	3	4	5	6	7	8	9	10	11
5. Food Science	Mode = 9	0	0	0	0	2	3	3	2	4	(3)	1	1	2	3	4	5	6	7	8	9	10	11
6. Food Safety	Mode = 8	0	0	1	0	1	1	0	6	(2)	4	3	1	2	3	4	5	6	7	8	9	10	11
7. Social Impact	Mode = 11	0	0	1	1	0	0	1	0	2	5	(7)	1	2	3	4	5	6	7	8	9	10	11
8. Plant & Animal Genetic Engineering	Mode = 11	0	0	0	0	0	0	0	1	4	5	(8)	1	2	3	4	5	6	7	8	9	10	11
9. Microbial Applications	Mode = 10	0	0	0	0	0	0	0	2	2	(9)	5	1	2	3	4	5	6	7	8	9	10	11

Your response from the Delphi II is circled.

SUBCATEGORIES	MODE	RESULTS OF DELPHI II (Frequency of Responses)											NEW RESPONSE										
		NOT IMPORTANT										CRITICAL	NOT IMPORTANT										CRITICAL
		1	2	3	4	5	6	7	8	9	10	11											
(AGRICULTURE) cont'd.																							
10. Plant & Animal Applications	Mode = 10	0	0	0	0	0	0	1	2	1	(10)	3	1	2	3	4	5	6	7	8	9	10	11
11. Agrichemicals	Mode = 10	0	0	1	0	0	1	3	2	2	(5)	3	1	2	3	4	5	6	7	8	9	10	11
12. Food Packaging	Mode = 8	2	0	1	1	1	3	3	(5)	0	1	1	1	2	3	4	5	6	7	8	9	10	11
(BIOCHEMISTRY)																							
1. Proteins	Mode = 11	0	0	0	0	0	0	0	1	5	3	(9)	1	2	3	4	5	6	7	8	9	10	11
2. Enzymology	Mode = 11	0	0	0	0	0	0	1	1	3	6	(7)	1	2	3	4	5	6	7	8	9	10	11
3. Methods of Analysis	Mode = 10	0	0	0	0	0	0	1	4	1	7	(5)	1	2	3	4	5	6	7	8	9	10	11
4. Macromolecular Structure	Mode = 11	0	0	0	0	1	0	2	2	4	3	(6)	1	2	3	4	5	6	7	8	9	10	11
5. Lipids	Mode = 8	0	0	0	1	0	1	2	5	4	1	(4)	1	2	3	4	5	6	7	8	9	10	11
6. Carbohydrates	Mode = 9	0	0	0	0	1	1	2	4	5	1	(4)	1	2	3	4	5	6	7	8	9	10	11
7. Control and Regulation	Mode = 11	0	0	0	0	0	0	1	2	3	(5)	7	1	2	3	4	5	6	7	8	9	10	11
8. The Genetic Material	Mode = 10,11	1	0	0	0	0	0	1	2	2	6	(6)	1	2	3	4	5	6	7	8	9	10	11
9. Social Impact	Mode = 11	3	0	1	0	0	1	1	2	1	2	(7)	1	2	3	4	5	6	7	8	9	10	11
(MEDICINE)																							
1. Genetic Therapeutics	Mode = 10	0	0	0	0	0	1	1	0	2	8	(6)	1	2	3	4	5	6	7	8	9	10	11
2. Molecular Medicine	Mode = 11	0	0	0	0	0	1	1	1	3	5	(7)	1	2	3	4	5	6	7	8	9	10	11
3. Health Care Technologies	Mode = 10	0	0	0	0	1	0	3	3	3	(6)	1	1	2	3	4	5	6	7	8	9	10	11
4. Medical Devices	Mode = 8,10	0	1	2	1	0	1	2	4	3	(4)	0	1	2	3	4	5	6	7	8	9	10	11
5. Immunology	Mode = 11	0	0	0	0	0	1	0	0	(4)	6	7	1	2	3	4	5	6	7	8	9	10	11
6. Social Impact	Mode = 11	0	0	0	1	1	0	0	0	0	(4)	12	1	2	3	4	5	6	7	8	9	10	11

Your response from the Delphi II is circled.

SUBCATEGORIES	MODE	RESULTS OF DELPHI II (Frequency of Responses)											NEW RESPONSE										
		NOT IMPORTANT										CRITICAL	NOT IMPORTANT										CRITICAL
(ENVIRONMENT)		1	2	3	4	5	6	7	8	9	10	11											
1. Biotreatment Systems	Mode = 11	0	0	0	0	1	0	3	0	4	3	(7)	1	2	3	4	5	6	7	8	9	10	11
2. Bioremediation	Mode = 11	0	0	0	0	0	1	1	2	1	5	(7)	1	2	3	4	5	6	7	8	9	10	11
3. Biological Controls	Mode = 10	0	0	0	0	0	0	1	2	2	8	(5)	1	2	3	4	5	6	7	8	9	10	11
4. Biorestoration	Mode = 10	0	0	0	0	0	1	1	2	4	5	(4)	1	2	3	4	5	6	7	8	9	10	11
5. Wildlife Management	Mode = 8	1	0	3	0	1	0	1	5	2	2	(3)	1	2	3	4	5	6	7	8	9	10	11
6. Safety	Mode = 10,11	0	0	0	0	0	1	2	2	3	(5)	5	1	2	3	4	5	6	7	8	9	10	11
7. Social Impact	Mode = 11	0	0	2	0	0	1	0	0	1	2	(12)	1	2	3	4	5	6	7	8	9	10	11
(BIOETHICS)																							
1. Principles of Ethics	Mode = 11	0	0	3	0	0	0	1	0	4	2	(8)	1	2	3	4	5	6	7	8	9	10	11
2. Patenting of Life	Mode = 11	0	0	1	1	0	0	0	3	4	4	(5)	1	2	3	4	5	6	7	8	9	10	11
3. Timetable for Development	Mode = 4,7,8	0	1	0	3	1	2	3	3	0	1	0	1	2	3	4	5	6	7	8	9	10	11
4. Impacts of Using Biotechnology	Mode = 11	0	0	0	1	0	0	0	1	4	4	(7)	1	2	3	4	5	6	7	8	9	10	11
5. Potentials of Gene Therapy	Mode = 11	0	0	0	1	0	1	0	1	2	6	(7)	1	2	3	4	5	6	7	8	9	10	11
6. Population Studies	Mode = 7	0	0	1	0	1	1	5	1	4	2	(2)	1	2	3	4	5	6	7	8	9	10	11
7. Forensics	Mode = 9	0	0	1	0	0	0	2	3	7	2	(3)	1	2	3	4	5	6	7	8	9	10	11
8. Technology Transfer	Mode = 8,10	1	0	0	0	1	0	3	4	2	4	(3)	1	2	3	4	5	6	7	8	9	10	11
9. Regulation: Legislation & Safety	Mode = 11	0	0	0	0	0	1	1	1	5	3	(7)	1	2	3	4	5	6	7	8	9	10	11
10. Social Impact	Mode = 11	0	0	0	1	0	0	0	1	1	2	(13)	1	2	3	4	5	6	7	8	9	10	11

Your response from the Delphi II is circled.

DOCUMENT B

Report of Delphi II Comments

COMMENTS FROM DELPHI II

* r = rating

BIOPROCESSING

1. **Fermentation**
   (r=10) for some processes in biotech fermentation is the best way of mass production

2. **Culturing**
   (r=11) pure cultures are essential

3. **Microbial Applications**
   (r=8) some new technologies are based on microbials
   (r = none) too vague to score
   (r = none) I don't understand how this is different than what I would assume are the subcategories of it; fermentation, biomass conversion, etc.

4. **Historical Overview**
   (r=5) not too important since much of biotech has a short history

5. **Microbial Structure**
   (r=7) only certain forms can be cultured
   (r=1) wouldn't this material be covered in #8 of Genetic Engineering? I'm assuming the basic cell structures would discuss procaryotic & eucaryotic cells

6. **Bio-Products**
   (r= none) Would these be described under the various processes that generate them - giving students a list is not very useful
   (r=8) end product is important

7. **Types of Microorganisms**
   (r=9) This is important, but wouldn't this be discussed in #3?
   (r=9) bacteria may be better than fungi or vice versa
   (r=9) If this is only classification.

8. **Bioreactor Design**
   (r=7) some sophistication required

9. **Separation and Purification Techniques**
   (r=7) fairly basic

10. **Processing Design: Monitoring and Growth**
    (r=7) fairly basic

11. **Bioelectronics and Bioworks**
    (r = none) Not familiar with term Bioworks.
    (r=3) What is it?
    (r = none) I'm not sure what this is supposed to be.

12. **Processing Types**
    (r=7) processing should be worked out
    (r = none) Are these the same [referring to #9, r=11)? Am unfamiliar with term "processing types".
    (r = none) I don't understand category - processing procedures?
    (r = none) What does this refer to?

14. **Bioprocessing of Fossil Fuels**
    (r=6) not familiar with process
    (r = none) If this refers to breakdown of fossil fuels, it should be under "Environment."

15. **Genetic Engineering**
    (r=1) This is covered in area of same name.
    (r = none) Already a major category.
    (r=10) often based on genetic engineering

16. **Packaging**
    (r=5) already worked out
    (r = none) Packaging of what?

17. **Social Impact**
    (r=8) Social impact could be very positive but there is a negative component that requires education of the public.
    (r=11) In many cases this will impact people at the core of their beliefs.

INTRODUCTION OF BIOTECHNOLOGY

1. **Career Information**
   (r=11) We need to expose students to opportunities in this field.
   (r=1) Vague - sounds like a counselling function.
   (r=7) Not to be overdone.

2. **Career Preparation**
   (r=5) Depends on focus of course; is this course designated as vocational? If not, then career prep is less essential.
   (r=1) Vague - sounds like a counselling function.

3. **Profiles of Biotechnology Companies**
   (r=3) Scientific or Business class?
   (r=5) Only to understand relationships to education, capital, etc.

4. **Relevant Terms**
   (r=1) Should be provided in context of other topics.
   (r=9) Avoid jargon.
   (r=9) The technical terms should be conceptually taught and not simply memorized.
   (r=5) Terms change; some become jargon.

5. **Definition of Biotechnology**
   (r=1) Everybody has their own.
   (r=4) Must define, but it should be well understood.
   (r=9) Again, biotechnology definitions should be conceptually taught.
   (r=3) This depends on what group is defining it and is changeable.

6. **Historical Background**
   (r=4) Very little history.

7. **Laboratory Safety**
   (r=11) This is a strange place to put this topic - the rest of these categories sound like lecture, not lab material.
   (r=1) Should be presented in context of a lab course.
   (r=11) Important to workers in the field.
   (r=11) If laboratory exercises are part of the curriculum, this would be very critical.

8. **Scientific Method**
   (r=6) Some of biotech is emperical, but it should be based on scientific information.
   (r=1) Should have been presented in 1st science course students ever take.
   (r=11) This is one way to make teaching biotechnology meaningful and conceptual.
   (r=10) The more relevant point is to foster an understanding of the difference between science and technology.

9. **Specifications on Lab Journals and Logs**
   (r=1) Should be presented in lab course.
   (r=10) document for patent application
   (r=8) Hopefully this would be introduced here and each area would reinforce specifics.
   (r=10) It is critical as a process in the scientific method.

10. **Social Impact**
    (r=8) Must be accepted by public.
    (r=9) Introduce the social impact here and continue in-depth in Ethics.
    (r=11) This is very important to develop decision making skills of students regarding the use of biotechnology.

GENETIC ENGINEERING

1. **History & Ethics**
   (r = none) Already covered under social impact.
   (r=10) Must not be misused.
   (r=4) Ethics can be reinforced, but should be discussed in item #10 of Bioethics.

2. **Probing Techniques**
   (r=10) Monitoring is essential.
   (r = none) Subcategory of #3.
   (r=11) I would think <u>all</u> techniques would be discussed in item #10 (of this knowledge area).

3. **Analysis of DNA**
   (r=11) Probably critical - but "analysis" is too vague to be meaningful.
   (r=11) I would think <u>all</u> techniques would be discussed in item #10 (of this knowledge area).

4. **Basic Research**
(r=6) much can be applied
(r = none) Too vague.
(r = none) Too general to be a subcategory - could apply to any science.
(r=11) especially with #1 History - how basic research led to this.
(r=7) I'm not clear on what this indicates. Are you describing career, desinging experiments, or discussing applications?
(r=8) If the main point is technology education, reports and in-depth exposure to "basic research" is nice, but not critical.

6. **Vector Systems**
(r=10) Important for gene transfer.

9. **Genome Projects**
(r=7) I would either combine this with item 11 (of this knowledge area), or have it included in item #10 of Bioethics.
(r=10) Important for understanding genetic makeup.
(r=3) Current topics of interest category.

10. **Molecular Bio Techniques**
(r = none) What does this mean? For many it might be equivalent to "Genetic Engineering."

12. **Marine Biotechnology**
(r=9) Important, but why not put this subcategory into the agriculture knowledge area?
(r = none) Does not belong in this category. It is a field of application of technology, like agriculture.
(r=8) Should not be that different to be a category by itself.

13. **Social Impact**
(r=8) May be hard to sway general public.
(r = none) Already covered in another major category.
(r=2) I feel the genetic engineering knowledge area should be devoted to the actual techniques & theories. The social impact should be handled in ethical discussions.

AGRICULTURE

1. **Tissue Culturing**
(r=9) Important for some areas.
(r=11) Possibly under "Genetic Engineering" also.

2. **Plant Physiological Systems**
(r=5) Physiology important but not necessarily critical to technology.

3. **Animal Physiological Systems**
(r=5) Physiology important but not necessarily critical to technology.

4. **Aquaculture**
(r=6) May develop aquaculture faster than now.

6. **Food Safety**
(r=10) Can monitor harmful organisms.
(r=11) Especially with microbiology.

7. **Social Impact**
(r=3) Once again - I think social impacts belongs to ethics - area specific itiems can be discussed, but the Knowledge Area should deal with the "nuts and bolts" of that area.
(r=10) Could revolutionize agriculture.
(r = none) Already covered in another major category.

9. **Microbial Applications**
(r=11) Inaccurate choice of word ("application"); one does not a microbe to something.

10. **Plant & Animal Applications**
(r = none) Inaccurate choice of word ("application"); one does not a plant or animal to something.

11. **Agrichemicals**
(r=6) Is this about bioprocess production - item #6 in Bioprocessing?
(r=3) Will probably displace them.

12. **Food Packaging**
(r=3) Packaging should not change.

BIOCHEMISTRY

1. **Proteins**
   (r = 10) Basis of manifestation of genes

2. **Enzymology**
   (r = 10) Workhorse of metabolism.

3. **Methods of Analysis**
   (r = 10) Good mehtods required.

5. **Lipids**
   (r = 6) As they interact with proteins are important.

7. **Control and Regulation**
   (r = 10) Basis for much of objectives in Biotechnology.

9. **Social Impact**
   (r = 1) Treated elsewhere.
   (r = 3) May not have direct effects on society.

MEDICINE

1. **Genetic Therapeutics**
   (r = 6) Possible in a limited way.

3. **Health Care Technologies**
   (r = 10) Already changing.
   (r = none) Too broad - not clear what it means.

4. **Medical Devices**
   (r = 10) New instrumentation important.

5. **Immunology**
   (r = 6) I think this belongs under Biochemistry. You could discuss medical applications of immunology techniques here, but the acutal study of immunology fits better under Biochem.
   (r = 10) Very important to biotechnology.
   (r = 11) This is one of four core areas for teaching biotechnology - fundamental concepts.

ENVIRONMENT

1. **Biotreatment Systems**
   (r = 7) Much needs to be learned.
   (r = 11) This could be the same as Bioremediation or Biorestoration.

2. **Bioremediation**
   (r = none) Don't know this term.

3. **Biological Controls**
   (r = 8) Many will be developed but not a panacea.
   (r = 11) If for insects or other pests, is it more appropriate in agriculture?

4. **Biorestoration**
   (r = 10) I'm not sure what this is.

5. **Wildlife Management**
   (r = 8) If you mean creating DNA libraries of endangered speicies & management of controlled breading programs.
   (r = 3) May not be possible.

7. **Social Impact**
   (r = 6) May be useful, but limited. We have to learn to take care of the environment we have and not try to change it.

BIOETHICS

1. **Principles of Ethics**
   (r=3) "Ethics" per se is less important than value clarification and understanding how policy is made and without assumption.
   (r=11) Technology can be misused.
   (r=11) The word "ethics" is being used in a very loose sense. Better choice might be "Impacts of using biotechnology", or "Social Impact."
   (r=9) Methods of ethics is far more important.

3. **Timetable for Development**
   (r=5) Is this the development of the field, or development of specific products? The former should be covered under item #6 in Introduction to Biotechnology. The latter could be relevant if related to offical approval of developed products, ie. FDA approval of new drug treatments.
   (r=4) This will develop at its own pace.
   (r = none) I do not understand category.
   (r = none) Not sure what is meant.

4. **Impacts of Using Biotechnology**
   (r=11) How does this differ from Social Impacts (#10)?
   (r=10) Could be very positive, but should guard against negatives.

5. **Potentials of Gene Therapy**
   (r=11) High interest area in medicine.
   (r=4) Some few cases may be possible to achieve, but gene therapy should not be misused.

6. **Population Studies**
   (r=11) High interest area in crime prevention.
   (r = none) What kind of studies? For what purposes?
   (r=3) Not sure how it might apply.

7. **Forensics**
   (r=10) Already proven useful with PCR.
   (r=11) High interest area.

8. **Technology Transfer**
   (r=10) Must be transferred to industry.
   (r=1) Not a topic important for students.

9. **Regulation: Legislation & Safety**
   (r=11) Must be carefully monitored but not to detriment of progress.

DOCUMENT C

Reason Sheet for Remaining Outside Consensus

REASONS FOR REMAINING OUTSIDE THE CONSENSUS

BIOPROCESSING

1. **Fermentation**
   Reason:

2. **Culturing**
   Reason:

3. **Microbial Applications**
   Reason:

4. **Historical Overview**
   Reason:

5. **Microbial Structure**
   Reason:

6. **Bio-Products**
   Reason:

7. **Types of Microorganisms**
   Reason:

8. **Bioreactor Design**
   Reason:

REASONS FOR REMAINING OUTSIDE THE CONSENSUS

BIOPROCESSING (cont'd.)

9. **Separation and Purification Techniques**
   Reason:

10. **Processing Design: Monitoring and Growth**
    Reason:

11. **Bioelectronics**
    Reason:

12. **Processing Types**
    Reason:

13. **Biomass Conversion**
    Reason:

14. **Bioprocessing of Fossil Fuels**
    Reason:

15. **Genetic Engineering**
    Reason:

16. **Packaging**
    Reason:

17. **Social Impact**
    Reason:

INTRODUCTION TO BIOTECHNOLOGY

1. **Career Information**
   Reason:

2. **Career Preparation**
   Reason:

3. **Profiles of Biotechnology Companies**
   Reason:

4. **Relevant Terms**
   Reason:

5. **Definition of Biotechnology**
   Reason:

6. **Historical Background**
   Reason:

7. **Laboratory Safety**
   Reason:

8. **Scientific Method**
   Reason:

9. **Specifications on Lab Journals and Logs**
   Reason:

10. **Social Impact**
    Reason:

REASONS FOR REMAINING OUTSIDE THE CONSENSUS

GENETIC ENGINEERING

1. **History and Ethics**
   Reason:

2. **Probing Techniques**
   Reason:

3. **Analysis of DNA**
   Reason:

4. **Basic Research**
   Reason:

5. **Genetic Code**
   Reason:

6. **Vector Systems**
   Reason:

7. **Basic Structures of Genetic Material**
   Reason:

8. **Basic Cell Structures**
   Reason:

9. **Genome Projects**
   Reason:

10. **Molecular Bio Techniques**
    Reason:

11. **Genetic Engineering Applications**
    Reason:

12. **Marine Biotechnology**
    Reason:

13. **Social Impact**
    Reason:

AGRICULTURE

1. **Tissue Culturing**
   Reason:

2. **Plant Physiological Systems**
   Reason:

3. **Animal Physiological Systems**
   Reason:

4. **Aquaculture**
   Reason:

5. **Food Science**
   Reason:

6. **Food Safety**
   Reason:

7. **Social Impact**
   Reason:

8. **Plant and Animal Genetic Engineering**
   Reason:

9. **Microbial Applications**
   Reason:

REASONS FOR REMAINING OUTSIDE THE CONSENSUS

AGRICULTURE (cont'd.)

10. **Plant and Animal Applications**
Reason:

11. **Agrichemicals**
Reason:

12. **Food Packaging**
Reason:

BIOCHEMISTRY

1. **Proteins**
Reason:

2. **Enzymology**
Reason:

3. **Methods of Analysis**
Reason:

4. **Macromolecular Structures**
Reason:

5. **Lipids**
Reason:

6. **Carbohydrates**
Reason:

7. **Control and Regulation**
Reason:

8. **The Genetic Material**
Reason:

9. **Social Impact**
Reason:

MEDICINE

1. **Genetic Therapeutics**
Reason:

2. **Molecular Medicine**
Reason:

3. **Health Care Technologies**
Reason:

4. **Medical Devices**
Reason:

5. **Immunology**
Reason:

6. **Social Impact**
Reason:

REASONS FOR REMAINING OUTSIDE THE CONSENSUS

ENVIRONMENT

1. **Biotreatment Systems**
   Reason:

2. **Bioremediation**
   Reason:

3. **Biological Controls**
   Reason:

4. **Biorestoration**
   Reason:

5. **Wildlife Management**
   Reason:

6. **Safety**
   Reason:

7. **Social Impact**
   Reason:

BIOETHICS

1. **Principles of Ethics**
   Reason:

2. **Patenting of Life**
   Reason:

3. **Timetable of Development**
   Reason:

4. **Impacts of Using Biotechnology**
   Reason:

5. **Potentials of Gene Therapy**
   Reason:

6. **Population Studies**
   Reason:

7. **Forensics**
   Reason:

8. **Technology Transfer**
   Reason:

9. **Regulation: Legislation and Safety**
   Reason:

10. **Social Impact**
    Reason:

APPENDIX G

Main Knowledge Areas,

Subdivisions and Content Categories

DOCUMENT A

List of Main Knowledge Areas Submitted

Educational Orgainzations

- Environmental Management
- BioEnergy Management & Production
- Bio Materials
- Regulations, Legislation & Safety
- Human Application
- Industrial Application
- Agricultural Applications
- Genetics
- Bacteriology
- Plant Tissue Culture
- Cell Biology
- Science, Technology and Society
- Bioethics
- Cell Biology and Physiology of Microbes
- DNA Chemistry
- Regulation of Gene Activity
- Protein Structure and Function
- Enzyme Activity

- Antibody-Antigen Interactions
- Food and Consumer Products
- Pharmacueticals, Diagnostics and Forensics
- Fermentation
- Fears and Ethical Considerations
- Biotechnology In The Outdoor Environment
- Biotechnology In Agriculture
- Genetic Engineering
- General Biochemistry
- Purification/Separation
- DNA
- Problem Solving
- Bioethics
- Processes of Biotechnology
- Applications of Biotechnology
- Medicine
- Environmental
- Careers in Biotechnology

Biotechnology Companies

- Medicine

- Food
- Law
- Ecology/Environment
- Archaeology
- Chemical Industry
- Insurance
- Health
- Pollution
- Agriculture
- Wildlife Conservation
- Evolution
- Forensics
- Genetics
- Biochemistry (proteins)
- Microbiology (bacteria)
- Cell Biology (plant & animal)
- Technology
- Society Choices
- Medical Applications
- Animal Science Applications
- Environmental Applications

- Plant Sciences
- Sustainable Development
- Cell Biology
- Genetics & Molecular Biology
- Biochemistry
- Microbiology
- Immunology
- Applications
- Social, Political and Ethical Issues
- Career Information

Universities

- Introduction to Field of Biotechnology
- Basic Genetics and Genetic Engineering
- Impacts of Biotechnology
- Biotechnology in Plant Science
- Biotechnology in Animal Science
- Microbial Applications
- Processes of Biotechnology
- Science
- Traditional Biotechnology

- Agriculture
- Human DNA (traditional)
- Human DNA (recombinant)
- Pharmaceuticals
- Societal Issues
- Microbiology
- Cell Biology
- Immunology
- Molecular Biology
- Understanding the Cell
- DNA - The Genetic Material
- Gene Transfer and Expression
- The Genetics of Prokaryotes
- Recombinant DNA Technology
- Other Biotechnologies
- Applications of Biotechnology
- Ethical Considerations in Biotechnology
- Microbial Biotechnology
- Plant Cell Cultures
- Animal Cell Culture
- Biomaterials

- Regulation
- Sociatal Issues and Policy Decesions
- Biology
- Public Policy

Government Agencies

- Agriculture
- Energy
- Environment
- Health
- Manufacturing/Bioprocessing
- Genome Projects
- Marine Biotechnology
- Structural Biology
- Medicine
- Food Production (agriculture)
- Food Processing
- Space Technology
- Biodiversity
- Biochemistry
- Fermentation

- Recombinant DNA
- Recombinant DNA Products
- Plant and Animal Cell Tissue Culture
- Biosensors
- History of Biotechnology
- Laboratory Techniques
- Molecular Biology Techniques
- Commercial Applications of Biotechnology
- Cultural Impacts

DOCUMENT B

List of Main Knowledge Areas, Subdivisions

and Instructional Content Categories

BIOPROCESSING

	SUBDIVISIONS	CONTENT CATEGORIES
1.	**FERMENTATION**	brewing medium formulation optimization downstream processing immobilized cells
2.	**CULTURING**	bacterial culturing tissue culturing yeast culturing culturing E.coli
3.	**MICROBIAL APPLICATIONS**	microbial soil agriculture microbial protection of food dairy foods microbial water & waste applications pharmaceutical environmental microbiology clinical microbiology plant & animal cell-derived products
4.	**HISTORICAL OVERVIEW**	time line of science
5.	**BIO-PRODUCTS**	antibiotics future products disease biocompatible materials immunotechnologies

		bimolecular materials non-pharmaceutical bioproducts low & high molecular weight products
6.	**MICROBIAL STRUCTURE**	mutations chromosomes of E.coli DNA: define & understand plasmid DNA whole cell differentiation cell division organization of cells in tissue
7.	**TYPES OF MICROORGANISMS**	nature of E.coli prokaryotes vs. eukaryotes
8.	**BIOREACTOR DESIGN**	scaling up instrumentation
9.	**SEPARATION & PURIFICATION TECHNIQUES**	
10.	**PROCESSING DESIGN: MONITORING & GROWTH**	methods of analysis parameters of growth and their monitoring protein factories for cloned genes
11.	**BIOELECTRONICS & BIOWORKS**	diagnostics biosensors biological solar energy conversion commercial applications integrated biochips enzyme-coupled electrodes

12.	**BIOMASS CONVERSION**	biocatalysis
13.	**BIOPROCESSING OF FOSSIL FUELS**	
14.	**PROCESSING TYPES**	processes dependent of microbial Metabolisms
15.	**GENETIC ENGINEERING**	operon & repressor genes bacterial transformation bacterial genetics tissue engineering materials metabolic engineering monoclonal Ab techniques viruses as vectors cell to cell communication lysis conjugation retrovirus regulator gene transduction cell fusion
16.	**PACKAGING**	
17.	**SOCIAL IMPACT**	

FOUNDATIONS IN BIOTECHNOLOGY

SUBDIVISIONS	CONTENT CATEGORIES
1. **CAREER INFORMATION**	
2. **CAREER PREPARATION**	

3.	**PROFILES OF BIOTECHNOLOGY COMPANIES**	
4.	**RELEVANT TERMS**	
5.	**DEFINITION OF BIOTECHNOLOGY**	
6.	**HISTORICAL BACKGROUND**	Food Fermentation plant/animal breeding genetics/Mendel Watson/Crick Cohen/Boyer
7.	**LABORATORY SAFETY**	laboratory techniques equipment
8.	**SCIENTIFIC METHOD**	
9.	**SPECIFICATIONS ON LAB JOURNALS AND LOGS**	

BIOETHICS

	SUBDIVISIONS	CONTENT CATEGORIES
1.	**PRINCIPLES OF ETHICS**	decision making models persuasion skills playing God privacy issues justice: access concerns human germ line vs. somatic cell genetic engineering

2.	**PATENTING OF LIFE**	transgenic organisms intellectual property
3.	**TIMETABLE OF DEVELOPMENT**	
4.	**IMPACTS OF USING TECHNOLOGY**	biological warfare risk of not using technology benefits of biotechnology public acceptance of new technology concerns of biotechnology health care impacts social impacts individual impacts public perceptions
5.	**POTENTIALS IN GENE THERAPY**	human DNA cloning genetic defect testing gene therapy genetic counseling genetic tendency testing implications of human genome project application/implication of human genetic sequencing
6.	**POPULATION STUDIES**	extant and extinct species identification phylogeny
7.	**FORENSICS**	detection of future diseases paternity testing DNA finger printing
8.	**REGULATION: LEGISLATION & SAFETY**	dangerous accidents environmental destruction biosafety ecological concerns environmental impacts regulations food and drug

		public policy agricultural impacts field testing and regulation release of bioengineered organisms regulation of industry by scientific and government communities
9.	**TECHNOLOGY TRANSFER**	meeting needs of growing world population industrial impacts government funding

GENETIC ENGINEERING

	SUBDIVISIONS	CONTENT CATEGORIES
1.	**HISTORY & ETHICS**	human therapy social impact genetic counseling animal welfare issues
2.	**PROBING TECHNIQUES**	monoclonal Ab's cell chemical signals antibodies probes & biosensors radioactive probes diagnostic technology
3.	**ANALYSIS OF DNA**	jumping genes (transponsons) DNA extraction and analysis evolution screening methods for recombinants methods of analysis lambda DNA chemical DNA genetic organization

		stages in transfer of genetic material strain selection taxonomy DNA replication
4.	**BASIC RESEARCH**	cell growth plant/animal cells vs. bacteria environments human genetic diseases organization of living material
5.	**GENETIC CODE**	mutagenesis inheritance & mutation gene expression transcription and translation recognition sequences regulation of gene activity reverse transcription natural genetic engineering molecular genetics Mendel's Laws genetic diseases mechanisms of genetic exchange control of gene expression Northern Hybridization
6.	**VECTOR SYSTEMS**	viruses Ti plasmids
7.	**BASIC STRUCTURES OF GENETIC MATERIAL**	gene structure chromosome: division & replication gene expression regulators phylogenetic relationships
8.	**BASIC CELL STRUCTURES**	cell DNA nucleic acid metabolism

9. **GENOME PROJECTS**
   - population diversity
   - humane genome
   - plant genome
   - animal genome

10. **MOLECULAR BIOLOGY TECHNIQUES**
   - restriction fragments
   - polymerase chain reaction
   - transgenics
   - autoradiology
   - restriction enzymes
   - enzymes
   - ligation of DNA
   - chemical synthesis of DNA
   - DNA amplification and sequencing
   - gel electrophoresis
   - molecular hybridization
   - biological separation
   - selectable markers
   - heterologous expression

11. **GENETIC ENGINEERING APPLICATIONS**
   - molecular cloning
   - animal health
   - bioremediation
   - medicines
   - animal productivity
   - gene therapy
   - biodegradable materials
   - synthetic tissues
   - principles and techniques of genetic engineering
   - production of pharmaceutical
   - RFLP's
   - DNA fingerprinting
   - efficient production for farmer's resources
   - metabolically engineered organisms

12. **MARINE BIOTECHNOLOGY**	molecular genetics of marine organisms biofilms bimolecular materials & biosensors biocorrosion primary & secondary metabolism bioprocessing bioremediation aquaculture oceanic processes social impact

AGRICULTURE

SUBDIVISIONS	CONTENT CATEGORIES
1. **TISSUE CULTURING**	plant cell culturing insect cell culturing methodology
2. **PLANT & ANIMAL SYSTEMS**	disease organelles growth cycles metabolism structures computerized monitoring physiology methods of analysis vegetative propagation disease resistant plants salt/drought resistant plants transformation systems expressive vectors insect resistance large-scale animal tissue culture
3. **AQUACULTURE**	

4.	**FOOD SCIENCE**	food processing processing improvements processing applications
5.	**FOOD SAFETY**	
6.	**SOCIAL IMPACT**	animal use in research
7.	**PLANT & ANIMAL GENETIC ENGINEERING**	plant genetic engineering developmental biology transgenic animals plant quality improvements cell fractionation Mendel's contributions principles of segregation genetically engineered substances transgenic plants development of high nutrient plants cloning development of high yield plants dominant traits development for xeric climates development of new species inheritance of sex allele interactions incomplete dominance linkage principles of independent assortment recessive traits meiosis & sexual reproduction sex-linked traits gene interactions polygenic inheritance recombination transgenic plants
8.	**AGRICHEMICALS**	pharmaceutical specialty chemicals polymers

9.	**FOOD PACKAGING**	
10.	**MICROBIAL APPLICATIONS**	microbial food products micropropogation
11.	**PLANT & ANIMAL APPLICATIONS**	immunology herbicide resistance insect control plant disease control plants as factories integrated pest control management hydroponics mechanized agriculture biocontrols marketing pest control medicine bioremediation energy

BIOCHEMISTRY

	SUBDIVISIONS	CONTENT CATEGORIES
1.	**PROTEINS**	structure receptors purification function environment
2.	**ENZYMOLOGY**	restriction enzymes enzymatic engineering
3.	**METHODS OF ANALYSIS**	plasmids analysis of structure & functional relations determination of structure pH buffers and water
4.	**MACROMOLECULAR STRUCTURES**	macromolecular synthesis

5. **LIPIDS**

6. **CARBOHYDRATES**

7. **CONTROL & REGULATION**	antibiotic resistance metabolic pathways photosynthesis metabolisms
8. **THE GENETIC MATERIAL**	eukarayotic genes translation prokaryotic mutations nucleic acids transcription DNA structure amino acid sequences DNA properties concept of gene extrachromosomal DNA packaging of DNA introns DNA in prokaryotes extraction of DNA structure of protein types of RNA protein synthesis chromosomal DNA from genes to proteins exon transposon nucleosome DNA in eukaryotes

MEDICINE

SUBDIVISIONS	CONTENT CATEGORIES
1. **GENETIC THERAPEUTICS**	genetic cures Mendelian genetics gene therapy genetic screening inheritance gene banks
2. **MOLECULAR MEDICINE**	pharmaceutical drug discovery rDNA science identification of probes non-protein drugs energy transducers molecular genetics protein drugs human genome project nucleic acids (as probes & agents)
3. **HEALTH CARE TECHNOLOGIES**	clinical diagnosis next frontier disease prevention enzyme environments patient monitoring diagnostic detection immobilization of enzymes enzyme applications reaction times of enzymes enzyme uses
4. **IMMUNOLOGY**	antibodies cellular immunology humoral immunology intercellular communication immunoassays vaccines viral diseases

		Ab's engineered like enzymes Ab recognition Ab binding capabilities
5.	**MEDICAL DEVICES**	prostheses ergonomics microsurgery bionics implants
6.	**SOCIAL IMPACTS**	

ENVIRONMENT

	SUBDIVISIONS	CONTENT CATEGORIES
1.	**BIOTREATMENT SYSTEMS**	harnessing helpful microbes ice minus plants conversion of fossil fuels recycling process of waste reduction biodegradable materials mining applications
2.	**BIOREMEDIATION**	reduction of air and water pollution prevention of bio-induced corrosion soil purification
3.	**BIOLOGICAL CONTROLS**	crop production and protection environmental risk assessment techniques
4.	**BIORESTORATION**	hazardous waste clean up metal extraction
5.	**WILDLIFE MANAGEMENT**	Bt & gypsy moths mating studies species preservation population studies
6.	**SAFETY**	
7.	**SOCIAL IMPACT**	

APPENDIX H

SUMMARY OF PANEL MEMBER COMMENTS FROM DELPHI II

Summary of Panel Member Comments from Delphi II

Subdivision	r = rating	Comment
(Bioprocessing)		
Fermentation	10	For some processes in biotechnology fermentation is the best way of mass production.
Culturing	11	Pure cultures are essential.
Microbial Applications	8	Some new technologies are based on microbials
	none	I don't understand how this is different than what I would assume are the subcategories of it; fermentation, biomass conversion, etc.
Historical Overview	5	Not too important since much of biotechnology has a short history.
Microbial Structure	7	Only certain forms can be cultured.
	1	Wouldn't this material be covered in #8 of Genetic Engineering? I'm assuming the basic cell structures would discuss procaryotic & eucaryotic cells.
Types of Microorganisms	9	This is important, but wouldn't this be discussed in #3?
	9	Bacteria may be better than fungi or vice versa.
	9	If this is only classification.

Subdivision	r = rating	Comment
Microorganisms (cont'd)		
Bioreactor Design	7	Some sophistication required.
Separation and Purification Techniques	7	Fairly basic.
Processing Design: Monitoring and Growth	7	Fairly basic.
Bioelectronics and Bioworks	none	Not familiar with term Bioworks.
	3	What is it?
	none	I'm not sure what this is supposed to be.
Bioprocessing of Fossil Fuels	6	Not familiar with process.
	none	If this refers to breakdown of fossil fuels, it should be under "Environment."
Processing Types	7	Processing should be worked out.
	none	Are these the same [referring to #9, r=11)? Am unfamiliar with term "processing types."
	none	I don't understand category -processing procedures?
	none	What does this refer to?
Genetic Engineering	1	This covered in area of same name.
	none	Already a major category.
	10	Often based on genetic engineering.

Subdivision	r = rating	Comment
Packaging	5	Already worked out.
	none	Packaging of what?
Social Impact	8	Social impact could be very positive, but there is a negative component that requires education of the public.
	11	In many cases this will impact people at the core of their beliefs.
(Foundations in Biotechnology)		
Career Information	11	We need to expose students to opportunities in this field.
	1	Vague - sounds like a counseling function.
	7	Not to be overdone.
Career Preparation	5	Depends on focus of course; is this course designated as vocational? If not, then career prep is less essential.
	1	Vague - sounds like a counselling function.
Profiles of Biotechnology Companies	3	Scientific or Business class?
	5	Only to understand relationships to education, capital, etc.
Relevant Terms	1	Should be provided in context of other topics.
	9	Avoid jargon.
	9	The technical terms should be conceptually taught and not simply memorized.
	5	Terms change; some become jargon.

Subdivision	r = rating	Comment
Definition of Biotechnology	1	Everybody has their own.
	4	Must define, but it should be well understood.
	9	Again, biotechnology definitions should be conceptually taught.
	3	This depends on what group is defining it and is changeable.
Historical Background	4	Very little history.
Laboratory Safety	11	This is a strange place to put this topic - the rest of these categories sound like lecture, no lab material.
	1	Should be presented in context of a lab course.
	11	Important to workers in the field.
	11	If laboratory exercises are part of the curriculum, this would be very critical.
Scientific Method	6	Some of biotechnology is empirical, but it should be based on scientific information.
Scientific Method	1	Should have been presented in 1st science course students ever take.
	11	This is one way to make teaching biotechnology meaningful and conceptual.
	10	The more relevant point is to foster an understanding of the difference between science and technology.
Specifications on Lab Journals and Logs	1	Should be presented in lab course.
	10	Document for patent application.
	8	Hopefully this would be introduced here and each area would reinforce specifics.
	10	It is critical as a process in the scientific method.

Subdivision	r = rating	Comment
Social Impact	8	Must be accepted by public.
	9	Introduce the social impact here and continue in-depth in Ethics.
	11	This is very important to develop decision making skills of students regarding the use of biotechnology.
(Genetic Engineering)		
History & Ethics	none	Already covered under social impact.
	10	Must not be misused.
	4	Ethics can be reinforced, but should be discussed in item #10 of Bioethics.
Probing Techniques		
	10	Monitoring is essential.
	none	Subcategory of #3.
	11	I would think all techniques would be discussed in item #10 (of this knowledge area).
Basic Research	6	Much can be applied.
	none	Too vague.
	none	Too general to be a subcategory - could apply to any science.
	11	Especially with #1 history - how basic research led to this.
	7	I'm not clear on what this indicates. Are you describing career, designing experiments, or discussing applications?
	8	If the main point is technology education, reports and in-depth exposure to "basic research" is nice, but not critical.
Vector Systems	10	Important for gene transfer.

Subdivision	r = rating	Comment
Genome Projects	7	I would either combine this with item 11 (of this knowledge area), or have it included in item #10 of Bioethics.
	10	Important for understanding genetic makeup.
	3	Current topics of interest category.
Molecular Bio Techniques	none	What does this mean? For many it might be equivalent to "Genetic Engineering."
Marine Biotechnology	9	Important, but why not put this subcategory into the agriculture knowledge area?
	none	Does not belong in this category. It is a field of application of technology, like agriculture.
	8	Should not be that different to be a category by itself.
Social Impact	8	May be hard to sway general public.
	none	Already covered in another major category.
	2	I feel the genetic engineering knowledge area should be devoted to the actual techniques & theories. The social impact should be handled in ethical discussions.
(Agriculture)		
Tissue Culturing	9	Important for some areas.
	11	Possibly under "Genetic Engineering" also.
Plant Physiological Systems	5	Physiology important but not necessarily critical to technology.

Subdivision	r = rating	Comment
Animal Physiological Systems	5	Physiology important but not necessarily critical to technology.
Aquaculture	6	May develop aquaculture faster than now.
Food Safety	10	Can monitor harmful organisms.
Social Impact	3	Once again - I think social impacts belongs to ethics - area specific items can be discussed, but the Knowledge Area should deal with the "nuts and bolts" of that area.
	10	Could revolutionize agriculture.
	none	Already covered in another major category.
Microbial Application	11	Inaccurate choice of word ("application"); one does not apply a microbe to something.
Plant & Animal Applications	none	Inaccurate choice of word ("application"); one does not apply a plant or animal to something.
Agrichemicals	6	Is this about bioprocess production - item #6 in Bioprocessing?
	3	Packaging should not change.
(Biochemistry)		
Proteins	10	Basis of manifestation of genes.
Enzymology	10	Workhorse of metabolism.
Methods of Analysis	10	Good methods required.
Lipids	6	As they interact with proteins are important.

Subdivision	r = rating	Comment
Control and Regulation	10	Basis for much of objectives in Biotechnology.
Social Impact	1	Treated elsewhere.
	3	May not have direct effects on society.
(Medicine)		
Genetic Therapeutics	6	Possible in a limited way.
Health Care Technologies	10	Already changing.
	none	Too broad - not clear what it means.
Medical Devices	10	New instrumentation important.
Immunology	6	I think this belongs under Biochemistry. You could discuss medical applications of immunology techniques here, but the actual study of immunology fits better under Biochemistry.
	10	Very important to biotechnology.
	11	This is one of four core areas for teaching biotechnology - fundamental concepts.
(Environment)		
Biotreatment Systems	7	Much needs to be learned.
	11	This could be the same as Bioremediation or Biorestoration.
Bioremediation	none	Don't know this term.
Biological Controls	8	Many will be developed but not a panacea.
	11	If for insects or other pests, is it more appropriate in agriculture?

Subdivision	r = rating	Comment
Biorestoration	10	I'm not sure what this is.
Wildlife Management		
	8	If you mean creating DNA libraries of endangered species & management of controlled breading programs.
	3	May not be possible.
Social Impact	6	May be useful, but limited. We have to learn to take care of the environment we have, and not try to change it.
(Bioethics)		
Principles of Ethics	3	"Ethics" per se is less important than value clarification and understanding how policy is made and without assumption.
	11	Technology can be misused.
	11	The word "ethics" is being used in a very loose sense. Better choice might be "Impacts of using biotechnology", or "Social Impact."
	9	Methods of ethics is far more important.
Timetable for Development	5	Is this the development of the field, or development of specific products? The former should be covered under item #6 in Foundations in Biotechnology. The latter could be relevant if related to official approval of developed products, ie. FDA approval of new drug treatments.
	4	This will develop at its own pace.
	none	I do not understand category.
	none	Not sure what is meant.

Subdivision	r = rating	Comment
Impacts of Using Biotechnology	11	How does this differ from Social Impacts (#10)?
	10	Could be very positive, but should guard against negatives
Potentials of Gene Therapy	11	High interest area in medicine.
	4	Some few cases may be possible to achieve, but gene therapy should not be misused.
Population Studies	11	High interest area in crime prevention.
	none	What kind of studies? For what purposes?
	3	Not sure how it might apply.
Forensics	10	Already proven useful with PCR.
	11	High interest area.
Technology Transfer		
	10	Must be transferred to industry.
	1	Not a topic important for students.
Regulation: Legislation & Safety	11	Must be carefully monitored but not to detriment of progress.

APPENDIX J

INTERNAL COMMITTEE

Names of Internal Committee Members

Dr. R. Michael Akers, Ph.D.
Professor, Dairy Science
Virginia Polytechnic Institute & State University
Blacksburg, Virginia

Dr. Bert Newmark, M.D.
Diagnostic Imaging Radiology
Montgomery Regional Hospital
Blacksburg, Virginia

John G. Wells
NASA Research Associate
Virginia Polytechnic Institute & State University
Blacksburg, Virginia

VITA

EDUCATION and PROFESSIONAL DEVELOPMENT

Ph.D. **1992, Vocational Technical Education**
Virginia Polytechnic Institute and State University, Blacksburg, VA

M.S. **1990, Vocational Technical Education**
Virginia Polytechnic Institute and State University Blacksburg, VA

B.A. **1979, Biological Science**
Florida State University, Tallahassee, FL

B.A. **1978, Industrial Arts Education**
Florida State University, Tallahassee, FL

EMPLOYMENT HISTORY

1989 - 1992 **Graduate Research Associate, NASA Fellowship**
Virginia Polytechnic Institute and State University Blacksburg, VA

7/90 & 7/91 **Biotechnology Instructor**, Virginia Governor's School of Technology, Virginia Polytechnic and State University Blacksburg, VA

1979 -1989 **Secondary Biological/Technology Education Instructor**
Antilles Consolidated School System (Civil Service)
U.S. Naval Station, Ceiba, Puerto Rico

1979 - 1980 **Science and Reading Instructor for Dyslexic and Hyperkinetic students**
Woodland Hall Academy, Tallahassee, FL

HONORS and ACTIVITIES

9/91 **National Panel Member**, Challenger Center for Space Science Education, National Selection Panel for McAuliffe Fellowship Recipients

11/90 **Challenger Center Steering Committee Member**, Development of National Faculty Conference and Workshop Materials

12/89	**Challenger Center Steering Committee Member**, Development of space Teaching Package
1988 to Date	**National Faculty**, Challenger Center for Space Science Education
1987 to Date	**NASA Space Ambassador**, NASA Aerospace Educator
1985 to Date	**National Finalist, NASA Teacher In Space Project**

PROFESSIONAL ASSOCIATIONS

Member, NASA Teacher In Space (TIS)
Member, Challenger Center for Space Science Education (CCSSE)
Member, International Technology Education Association (ITEA)
Member, Council on Technology Teacher Education (CTTE)
Member, Virginia Technology Education Association (VTEA)
Member, Epsilon Pi Tau (EPT)
Member, Phi Delta Kappa (PDK)

PUBLICATIONS

- "Kids & Technology - Mission 21: Launching Technology Across the Curriculum." Teacher Resource Book, Level I. Delmar Publishers, 1992.
- "Algae, Electronics and Ginger Beer." *Technology, Innovation & Entrepreneurship for Students*. March - April, 1992.
- "Biotics: The more appropriate organizer?"; *The Technology Teacher*. Vol. 51, #3, Dec. 1991.

RESEARCH

- "Bovine Hormone Affects On Mouse Mammary Development." Mouse mammary tissue studies on the results of treatment with bovine prolactin and growth hormones. Virginia Polytechnic Institute & State University. Blacksburg, VA. 1990 - 1991.
- "Plant Tissue Culturing." Anther culture of potato embryos resulting from various growth media. Virginia Polytechnic Institute & State University. Blacksburg, VA. 1990.