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Introduction

Throughout the brief three-year history of the Minnesota Council on Biotechnology, the membership consistently agreed upon two basic factors: that the fundamental ingredient for Minnesota's ultimate success as a biotechnology leader will rely solely upon the resourcefulness of its educational system and its ability to respond to societal needs, and that Minnesota biotechnology must be a statewide effort to maximize economic impact and to best use the broadest range of natural resources and talents.

Although Minnesota is nationally known for its high regard for education, the knowledge explosion in biology within the past score of years has created an urgency to re-evaluate. We must question whether Minnesota's high school- and college-age students are afforded the opportunities to pursue modern biological concepts, and whether students are pursuing the high school chemistry, physics, computer science, and mathematics essential for biotechnology and other high technology careers. These questions will require quick attention to guarantee our students the competitive level of scientific understanding necessary to maintain Minnesota's high-technology posture.

Biology's time has come. Applications of biological principles are escalating in medicine, the pharmaceutical and food industries, agriculture, and in energy and chemical feedstock production. The impact of biotechnology in forthcoming decades will match the significance of the engineering programs that grew out of the physical sciences of the past century (1).

A recent study by the Minnesota Council on Biotechnology forecasts that Minnesota's biotechnology workforce will grow by an additional 32,000 to 50,000 people by the year 2000 (2). If, by the year 2000, the biotechnology workforce develops and matures as have similar applied professions in the physical sciences, e.g., engineering, then we should safely conclude that a significant percentage of the biotechnology workforce will be educated at the baccalaureate level and perhaps at the master level. To achieve this type of workforce, a network of information will need to be available to the public. A special effort will be required to enhance the conceptual development of biotechnology for junior high and senior high students, teachers, guidance counselors, and administrators.

Minnesota is in a unique position because it is one of only a few states with a comprehensive three-pronged approach to biotechnology education. The statewide approach includes doctoral level training at the University of Minnesota, baccalaureate programs at Mankato State University and St. Cloud State University, a biotechnology awareness program for high school teachers funded by the National Science Foundation (NSF), and several efforts funded by the Minnesota Higher Education Coordinating Board and various private foundations to do inservice science training in the K-6 schools. As past experience has shown, regardless of the loftiness of the aim at the university level, the educational foundation at the K-12 level is crucial for success.

Pre-College Education

Requirements to enhance biotechnology education in Minnesota are not greatly different than those of other science disciplines. High schools must offer and students must be encouraged to take four years of science and four years of mathematics as well as four years of written and oral communication coursework. In addition, the student must be able to appreciate the arts and be able to knowledgeably participate in sociopolitical events.

Several high schools are now beginning to develop courses in modern biology. This is timely; in fact, the content of modern biology should become a part of all biology programs. This is already underway in North Carolina and several other states. To do this, high school biology teachers will need assistance.

In a program funded by the NSF, Mankato State University has been training high school biology teachers in biotechnology for the past two years. The program titled Honors Workshop in Biotechnology Research for High School Teachers places a major emphasis on research in areas of modern biology important to biotechnology. The reason for the research emphasis is simple: too often science teachers have not had the opportunity to venture past the textbook and the formal laboratory to gain practical problem-solving experiences to make them feel comfortable as scientists.

Under the NSF-funded project, 20 biology teachers were brought on campus for a nine-week summer workshop. During that time the daily schedule started with a one-to-two-hour class on molecular biology followed by a two-to-three-hour laboratory on important techniques and methods such as thin-layer chromatography, electrophoresis, DNA separation, endonuclease enzyme work, and quantitative analysis of amino acid, proteins and lipids.

The afternoon schedule was unstructured so that each participant could work through the summer on a biotechnology project under the direction of a university faculty member. Examples of past summer projects include:

- Isolation of *Clostridium Perfringens* Type A antibody from mouse serum
- Isolation of bacteria from the earthworm gut with special enzyme systems
- Determination of bio-compatability of canine kidney epithelial cell on three-dimensional polymer substrates
- Attachment of *Agrobacterium tumefaciens* to dicot cells and plasmid transfer

The participants formed groups of four each week for writing sessions to develop high school biology laboratory and teaching materials from the lecture, laboratory, and research ideas given them. Also, the participants were taken on field trips to see a variety of biotechnology industries, and speakers were brought in to expose the teachers to industrial viewpoints.

This type of workshop helps teachers realize that modern biology is an essential part of the high school curriculum and that industrial applications can be used to teach these complex concepts. Currently, an acute shortage of basic equipment exists in the high school laboratory. Data collected from the 1985 workshop participants showed that most high schools do not have the necessary incubators, analytical balances, centrifuges, or basic spectrophotometers. The participants have become advocates for introducing additional instrumentation into the high school laboratory.

The program, funded again for the third year, has the same objectives as the past two years except that the summer commitment has been shortened to six weeks. Even though most of the activities occur during the summer, the participants are actively involved throughout an entire year starting with an early May meeting to introduce the workshop. Following the summer workshop, the teachers begin to introduce the materials into the high school curriculum. They are also committed to holding inservice workshops with teachers within their region to provide the "ripple effect" in order to get other teachers involved. Ideally, the honor teacher in the workshop should mentor 16 regional teachers to plant the seeds of biotechnology and provide any written materials the regional teachers may need.

Biology teachers fully realize the importance of biotechnology in fulfilling career choices for students interested in the natural sciences. As our agriculture, mining, and timber economy continues to change, substitute career options must be available. Biotechnology encompasses these areas and is a logical choice for many young people to make.

Undergraduate Biotechnology

Biotechnology can successfully be taught to undergraduates. It will increase their marketable skills, their opportunities for further education, and their appreciation of the complexities of the natural world. Accomplishing this goal requires a major commitment by the instructional staff in biotechnology-related classes and a concomitant commitment by college administrations to find the resources necessary to initiate and sustain quality programs.

Molecular biology and careers in biotechnology may seem overwhelmingly complex to the entering freshman. Therefore, one of the functions of the baccalaureate program is to provide an overview to clarify the perception of biotechnology and to build confidence as well as competence so that students do not become discouraged. For a freshman, gene splicing, cell fusion, and other such techniques may appear as unapproachable problems without the proper instructional encouragement.

To make an undergraduate program work in the allotted four years, the students must fulfill a rather rigorous schedule. Using the Mankato State University and St. Cloud State University baccalaureate programs as examples, the freshman and sophomore years are designed to provide students with a broad science and mathematics base. During the first two years, the programs require the students to take a full year of calculus, a year of inorganic and a year of organic chemistry, a year of physics, and two full years of biology.

Throughout the junior year, students focus on techniques and courses important to the biotechnologist, i.e., cell culture, fermentation, biochemistry, molecular biology, and instrumentation. Both universities view the student's skills in instrumentation as the key to successful entrance into the biotechnology profession. The senior year emphasis, along with appropriate coursework in advanced physiology and genetics, is on a biotechnology project. The project provides the student with the ability to apply knowledge to solve a problem. It also gives the student hands-on experience and confidence in using instrumentation of various types.

Other aspects of the undergraduate student's education must not be neglected in a biotechnology program. Because of the impact biotechnology will ultimately have on society, the student will need coursework in written and oral communications, economics, ethics, sociology, history, business, and the fine arts. It is estimated that more than 50% of the students will continue their education beyond the baccalaureate level. Therefore, a well-rounded background is required to assure student preparation for entry into graduate and professional schools.

The need for baccalaureate-trained biotechnology professionals will play a major role in the development of applied biology. Their importance to the industry laboratory will come from their conceptual, analytical, and instrumentation backgrounds, thus giving them the ability to understand the total project being pursued. In the workplace, the baccalaueate-trained biotechnologist would be the project leader who can take the ideas generated by senior scientists and be a successful product development and production leader.

Conclusion

Biotechnology cannot be based upon rote memory. The student pursuing this degree progam must be exposed to a broad spectrum of basic biological and physical science fundamentals; but to be successful, they must go beyond the formal classroom and gain practical applied experience solving real biotechnology problems. This must also include the library and use of journals and references on methodology so that the biotechnology major can be a synthesizer of ideas to enhance his or her professional growth potential in the industrial setting.

Biotechnologists and conventional biologists must also realize that a team approach is needed. For example, the present problems of using or releasing the few available biotechnology products into nature demonstrate our lack of understanding of complex ecological issues that exist. These issues should fuel the need for conventional biological programs rather than compete with them. Biotechnology may be the catalyst to revive and fund languishing areas of biology. It will certainly have a role in clarifying some of the elusive, complex riddles of biology important to all biologists.

References

1. Naisbitt, J. 1982. *Megatrends*. Warner Books. New York, NY.
2. Minnesota Council on Biotechnology. 1986. Economic impact of biotechnology. p. 99.