Individualizing Instruction Through Concept Assessment

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BIOLOGY AND BIOETHICS have become the focus of numerous articles in newspapers and magazines lately. These articles describe the latest applications of recent advances in our knowledge of medicine and biology. Unfortunately, these publications often employ erroneous and inadequate concepts of many biological and bioethical terms that are unfamiliar to the general public. At the same time, colleges and universities across the nation have introduced new courses such as human genetics and bioethical decision-making that focus on many of the same issues presented in the popular press.

Levels of understanding of new biological terms and concepts vary from student to student. To further complicate the problem, students' interpretations of the meaning of terms may differ from the scientific definitions used by their instructors. Thus, when students from different backgrounds come together in the biology classroom, an educational problem emerges. Because a single level of instruction frequently fails to attend to the various levels of student comprehension, instructors find it difficult to meet their students needs in the face of these conceptual differences.

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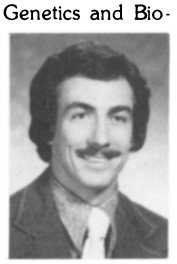

If instructors could determine their students' initial levels of understanding of bioethical terms and concepts, they would be more effective in helping students attain desired concept levels. This was the functional goal underlying the development of the Cognitive Biological Concept Assessment Instrument (CBCAI) described in this article.

Review of Pertinent Literature

An important factor in making a course accountable is determining the needs of the students with respect to the educational objectives of the course (Austin 1971; Glass 1972; Lieberman 1970; Lopez 1970; Merrill 1972; Park 1971; Primack 1971). To achieve this goal, the use of a preassessment instrument is essential (Geisert 1974; Park 1971; Silber 1974).

Many science course objectives stress the cognitive domain by emphasizing concept adequacy (Benson and Young 1971). Without the proper sequence of experiences or with limited experiences, concepts are often inadequately or erroneously formed (Novak 1966). The first step in determining concept entry behavior of students is to define terms at various levels of concept adequacy (Pella 1966). The creation of a cognitive concept adequacy instrument may enable course instructors to assess the concept entry levels of individual students. Obtaining data in this format should enable instructors to design educational strategies that are more meaningful (Bloom, *et al.* 1971; Hurst 1976).

During the past few years, major colleges and universities have developed bioethics courses or social biology courses that confront students with bioethical issues (Baer, Brant, and Pempel 1976; Hendrix 1977; Mathes and Chen 1976). The major issues stressed in these courses that require biological concept adequacy are: genetic engineering, reproductive technologies, human experimentation with free and informed consent, human behavioral control, health care, population control, environmental ethics, and the ethics of scientific research (Castleman 1974; Hurd 1975; Kieffer 1975; Melba, Schmidt, and Conley 1974).

Concept adequacy seems to depend on several personal characteristics of an individual: stage of cognitive development, previous experience with the concept, and the sequence of experiences with the concept (Anderson 1968; Novak 1966; Pella 1966). By setting a criterion of concept adequacy for individuals in the course, instructors can effectively measure the impact of instruction (Elsner 1973; McClelland 1973). Assessing concept entry behavior can provide data that will help in designing individualized instructional strategies (Bloom, Hastings, and Madaus 1971; Park 1971; Silber 1974). Individualization of instruction requires knowledge of entry behavior with respect to goals and objectives of the course (Geisert 1974; Hurst 1976).

Using various levels of Bloom's taxonomy of the cognitive domain to establish concept adequacy levels is a feasible method for use in instrument construction (Voelker 1973). A panel of experts who are at the synthesis level of concept adequacy for the biological concepts can establish face validity for the items in the instrument. Test/retest is an effective method for establishing instrument reliability (Thorndike and Hagen 1969).

Method

An instrument to measure the various levels of students' understanding of certain biological terms is necessary to achieve the goal of this project. Bloom's Taxonomy of Educational Objectives (1956) is the standard we chose to measure concept levels for each term used in the instrument.

Bloom divided learning into three domains: (1) psychomotor, which involves the mastering of physical skills; (2) cognitive, which is related to knowledge, concepts, and understanding; and (3) affective, which focuses on feelings, interests, and attitudes. Because we were attempting to determine the level of understanding of biological terms, we concentrated on Bloom's cognitive domain. Bloom subdivided cognitive domain into six levels, each of which was conceptually more advanced than its predecessor. The six cognitive levels from lowest to highest are: knowledge, comprehension, application, analysis, synthesis, and evaluation. Developing and using such an assessment instrument should enable an instructor to determine, given a specific bioethical or biological term, if a student has any idea of what the term means, if s/he knows a simple definition of the term (knowledge), if s/he truly comprehends what the term means (comprehension), or if his/her conceptualization of the term shows s/he uses abstractions (application, analysis, synthesis, or evaluation).

Development of the Instrument. We were interested in developing an instrument to assess the entry level of our students with respect to the concept objectives in three courses: Human Genetics and the Problems of Humankind, Bioethical Decision-Making, and freshman honors Symposium in Human Genetics and Bioethical Decision-Making. Over fifty articles in popular magazines, such as *Time* and *Newsweek*, were surveyed for concept terms used in these courses. From these articles, we compiled a list of 50 biological and bioethical terms by matching concept terms used in the articles with concept terms used in the course objectives.

The next step involved compiling as many different definitions of each term as was feasible; from these definitions, which were taken from books ranging from biological dictionaries through advanced genetics textbooks, three final composite definitions were created. Each definition was placed in a sequence based on an inferred hierarchy from the lowest to the highest conceptual level.

To establish content validity, a finished copy of the assessment instrument with the three definitions randomly sequenced was given to seven faculty members from the Department of Biology at Ball State University. The purpose of the instrument was explained to each faculty member, who was then asked to review the terms and rank each one of the three definitions from the one requiring the highest level of understanding to the one requiring the lowest level of understanding.

We evaluated the results and comments obtained from the faculty members and made several changes in the instrument. In almost all cases, however, the rankings offered by the faculty members were identical to the rankings we had previously established. The final instrument, which resembles a multiple-choice examination, is available on request.

Field Testing the Instrument. We assumed that individuals of different educational and experiential backgrounds with respect to human genetics and bioethics concepts would select the concept term definition appropriate to their educational attainments. To test this assumption, three populations of different biological educational levels were selected. The first population consisted of 38 high school sophomores and juniors enrolled in Academic Biology for the 1978-79 school year at Paul Harding High School, Ft. Wayne, Indiana; this group was taught by the third author. The second population included 12 college freshmen enrolled in Bio 100 during the spring quarter of the 1978-79 school year at Ball State University. The third population was composed of 39 high school life science teachers from various high schools throughout the state who had participated in a four-week NSF project entitled "Human Genetics and Bioethical Decision-Making for Secondary School Biology Teachers." Each population was assessed with the instrument prior to instruction in basic genetics, human genetics, and/or bioethics concepts.

Results and Discussion

Summaries of the data obtained from the three groups are found in tables 1 through 5. The three populations: high school students, college students, and high school teachers, were selected with the idea that members of the

different groups might be expected to exhibit different levels of understanding of the various terms included in the assessment instrument. If the assessment instrument is valid, the responses given by the teachers would be expected to be at a higher concept level than the responses of college freshmen and the college freshmen's responses would be expected to be at a higher concept level than the responses given by the high school students. For the most part, these expectations have been met.

The results are reported in five major groups: Mendelian genetics (table 1), human genetics (table 2), philosophy and ethics (table 3), reproductive physiology (table 4), and human behavioral control (table 5). These divisions will also be used in this discussion of the results.

Mendelian Genetics. The terms grouped under this heading make up the largest percentage (44%) of the instrument. Therefore, the results obtained for this group of terms are most important.

In every case the high school teachers recorded the same amount of, or fewer, "don't know" responses than either of the student groups (table 1). There were two terms, "mitosis" and "gene," for which both teachers and high school students recorded the same percentages (0% and 3% respectively).

For 17 out of the 22 terms, a larger percentage of the teachers chose the highest concept level response compared to the two student groups. The exceptions to this generalization were the terms "mitosis," "meiosis," "dominant gene," "epistasis," and "anticodon." A larger proportion of the college students chose the highest concept level response for 15 of the 22 terms when compared with the high school student population. The exceptions to this generalization were the terms "meiosis," "codon," and "gene." For four terms—"epistasis," "autosome," "allele," and "mosaic"—equal percentages were recorded for both student populations.

The results from the "don't know" and the highest concept level responses are the easiest to interpret. The results from the low and medium concept level responses are less conclusive. Logically, the high school and college students should record more low concept level responses than the teachers. In most cases, however, the opposite is true. Using the term "crossing over" as an example, note that 41% of the teachers chose the lowest concept level response, but only 25% of the college students and 21% of the high school students chose this response. These data appear to be inconsistent with the inferred results, unless the "don't know" responses are also examined. In this case, 61% of the high school students and 58% of the college students chose the "don't know" response; none of the high school teachers made this choice. A similar situation occurs for 15 other terms when they are compared with one or both of the student populations: "linkage," "meiosis," "gametogenesis," "epistasis," "autosome," "alleles," "codon," "RNA," "chromosome," "recessive gene," "phenotype," "non-disjunction," "sex linkage," "anticodon," and "mosaic."

A similar situation affects the results for the medium concept level responses. Normally, one would expect the teachers to choose a medium concept level response more often than the students. However, because the teachers chose the high concept level response so often, the number choosing the medium concept level response is often proportionately less. This situation occurs with the terms "segregation," "mutation," "codon," "recessive gene," "DNA," "RNA," and "mosaic."

Human Genetics. Terms related to human genetics (table 2) comprise 24% of the total instrument. Results from this group of terms were not quite as conclusive as the results from the Mendelian genetics terms. An examination of the "don't know" responses showed that for 11 of 12 terms, the percentage of teachers responding "don't know" was lower than the percentage of the students. The exception to this generalization was the term "reproductive cloning" to which 5% of the high school students, 0% of the college students, and 5% of the teachers responded "don't know."

For all but two terms, "pedigree" and "antibody," the high school students had the lowest percentage of high concept level responses. The teachers and the college students were split almost evenly as to which group chose the greatest percentage of the high concept level responses. For six terms—"eugenics," "karyotype," "reproductive cloning," "amniocentesis," "syndrome," and "Hardy-Weinberg Equilibrium"—a larger proportion of the teachers chose the high concept level response. For five terms—"polygenic inheritance," "antibody," "pedigree," "gene pool," and "gene surgery"—a larger fraction of the college students chose the high level concept response. For one term, "genetic counseling," the teachers and college freshmen tied.

The medium concept level response was chosen more often by the teachers than by either group of students in the human genetics section with the exception of the terms "reproductive cloning" and "syndrome." Once again, data from the number of low concept level responses proved inconclusive due to the high frequency of "don't know" responses given by the high school and college students.

A possible explanation as to why results from this group of terms is less conclusive than for Mendelian genetics terms could be that today's high school and college students are better informed about human genetics than even some of the science teachers are.

Philosophy and Ethics. Surprisingly, the results from this group of terms (table 3), which includes "naturalistic," "morals," "truth," "normative," "teleological" and "euthanasia," turned out to be more conclusive than we expected. Once again a larger fraction of the students gave "don't know" responses than did the teachers in each case except for the term "truth," which had both student populations giving a 0% response though 5% of the teachers gave that response.

A high concept level response was chosen more often

TABLE 1. Percentage of Individuals in Three Populations Responding to Mendelian Genetics Terms.

Terms	Never Heard Don't Know	Lowest Response	Medium Response	Highest Response
Segregation				
H.S. Sophomores and Juniors	34%	37%	18%	11%
College Freshmen	33	25	25	17
H.S. Science Teachers	5	3	18	74
Crossing over				
H.S. Sophomores and Juniors	61%	21%	13%	5%
College Freshmen	58	25	8	8
H.S. Science Teachers	0	41	34	24
Mutation				
H.S. Sophomores and Juniors	5%	61%	32%	3%
College Freshmen	8	50	25	17
H.S. Science Teachers	0	32	14	54
Linkage				
H.S. Sophomores and Juniors	18%	55%	18%	8%
College Freshmen	42	25	17	17
H.S. Science Teachers	3	36	26	36
Mitosis				
H.S. Sophomores and Juniors	0%	18%	53%	29%
College Freshmen	25	33	8	33
H.S. Science Teachers	0	3	71	26
Meiosis				
H.S. Sophomores and Juniors	3%	32%	3%	63%
College Freshmen	8	17	17	58
H.S. Science Teachers	0	23	21	56
Phenotype				
H.S. Sophomores and Juniors	39%	47%	8%	5%
College Freshmen	58	25	8	8
H.S. Science Teachers	0	33	44	23
Recessive gene				
H.S. Sophomores and Juniors	8%	74%	5%	13%
College Freshmen	36	9	9	45
H.S. Science Teachers	0	23	5	72
Gene				
H.S. Sophomores and Juniors	3%	81%	11%	5%
College Freshmen	17	58	25	0
H.S. Science Teachers	3	44	31	23
DNA				
H.S. Sophomores and Juniors	3%	37%	55%	5%
College Freshmen	33	25	33	8
H.S. Science Teachers	0	16	38	46
RNA				
H.S. Sophomores and Juniors	5%	53%	37%	5%
College Freshmen	58	25	8	8
H.S. Science Teachers	0	40	30	30
Chromosome				
H.S. Sophomores and Juniors	3%	71%	11%	16%
College Freshmen	17	33	25	25
H.S. Science Teachers	0	44	26	31
Dominant gene				
H.S. Sophomores and Juniors	5%	16%	37%	42%
College Freshmen	8	25	8	58
H.S. Science Teachers	0	47	11	42
Gametogenesis				
H.S. Sophomores and Juniors	42%	37%	16%	5%
College Freshmen	67	17	0	17
H.S. Science Teachers	11	24	32	34
Epistasis				
H.S. Sophomores and Juniors	95%	3%	3%	0%
College Freshmen	75	8	17	0
H.S. Science Teachers	59	24	16	0
Autosome				
H.S. Sophomores and Juniors	47%	34%	18%	0%
College Freshmen	83	0	17	0
H.S. Science Teachers	8	62	15	15
Alleles				
H.S. Sophomores and Juniors	21%	37%	34%	8%
College Freshmen	75	17	0	8
H.S. Science Teachers	13	33	44	10
Codon				
H.S. Sophomores and Juniors	45%	37%	11%	8%
College Freshmen	67	8	25	0
H.S. Science Teachers	10	46	10	33
Nondisjunction				
H.S. Sophomores and Juniors	74%	21%	5%	0%
College Freshmen	17	67	8	8
H.S. Science Teachers	13	49	18	21
Sex Linkage				
H.S. Sophomores and Juniors	41%	24%	32%	3%
College Freshmen	50	17	25	8
H.S. Science Teachers	0	32	41	27
Anticodon				
H.S. Sophomores and Juniors	54%	32%	11%	3%
College Freshmen	75	0	0	25
H.S. Science Teachers	37	32	21	11
Mosaic				
H.S. Sophomores and Juniors	89%	0%	11%	0%
College Freshmen	82	18	0	0
H.S. Science Teachers	46	31	8	15

TABLE 2. Percentage of Individuals in Three Populations Responding to Human Genetics Terms.

Terms	*Never Heard Don't Know*	*Lowest Response*	*Medium Response*	*Highest Response*
Eugenics				
H.S. Sophomores and Juniors	79%	8%	13%	0%
College Freshmen	42	17	25	17
H.S. Science Teachers	18	33	26	23
Karyotype				
H.S. Sophomores and Juniors	84%	0%	16%	0%
College Freshmen	33	42	25	0
H.S. Science Teachers	10	46	31	13
Gene Surgery				
H.S. Sophomores and Juniors	27%	46%	24%	3%
College Freshmen	25	42	25	8
H.S. Science Teachers	18	24	53	5
Reproductive Cloning				
H.S. Sophomores and Juniors	5%	50%	32%	13%
College Freshmen	0	25	58	17
H.S. Science Teachers	5	10	54	31
Amniocentesis				
H.S. Sophomores and Juniors	92%	5%	3%	0%
College Freshmen	50	0	25	25
H.S. Science Teachers	5	11	55	29
Gene pool				
H.S. Sophomores and Juniors	53%	39%	5%	3%
College Freshmen	33	25	25	17
H.S. Science Teachers	3	45	39	13
Syndrome				
H.S. Sophomores and Juniors	32%	50%	13%	5%
College Freshmen	25	33	25	17
H.S. Science Teachers	5	56	21	18
Pedigree				
H.S. Sophomores and Juniors	30%	38%	16%	16%
College Freshmen	25	17	17	42
H.S. Science Teachers	0	31	58	11
Genetic Counseling				
H.S. Sophomores and Juniors	24%	50%	5%	21%
College Freshmen	17	25	25	33
H.S. Science Teachers	3	33	31	33
Antibody				
H.S. Sophomores and Juniors	27%	38%	16%	19%
College Freshmen	25	17	17	42
H.S. Science Teachers	3	36	54	8
Hardy-Weinberg Equilibrium				
H.S. Sophomores and Juniors	100%	0%	0%	0%
College Freshmen	67	0	25	8
H.S. Science Teachers	28	28	28	15
Polygenic Inheritance				
H.S. Sophomores and Juniors	82%	13%	0%	5%
College Freshmen	75	0	8	17
H.S. Science Teachers	19	30	43	8

by teachers for every term except "naturalistic." For this term, 17% of the college students and only 5% of the high school teachers chose the high concept level response. The results from the medium and low concept level responses are inconclusive due once again to the effect of the low number of "don't know" responses and the high number of high concept level responses recorded by the teachers.

Reproductive Physiology. The terms from this group (table 4), which includes "tubal ligation," "AID," "*in vitro* fertilization," "abortion," and "diaphragm," yield results very similar to the results from the Philosophy and Ethics section. Generally teachers gave a "don't know" response less often than the students. A notable exception was the term "tubal ligation." For this term, 50% of the high school students, 8% of the college students, and 13% of the high school teachers gave a "don't know" response.

The results from the high concept level responses are also similar to those obtained in the Philosophy and Ethics section. A greater percentage of the teachers chose high concept level responses in all cases but one. The high concept level response for the term "tubal ligation" was chosen by 21% of the high school students, 67% of the college students, and 59% of the high school teachers.

Human Behavioral Control. The results for the four terms grouped under this heading (table 5), "biofeedback," "conditioning," "behavior modification," and "psychosurgery," are inconclusive. As one might expect, the students chose the "don't know" response more often than the teachers; yet the high concept level response was chosen by teachers more often for only one term—"biofeedback." For the remaining terms, the high concept level response was chosen by a higher percentage of college students than teachers. Although the results from this group are contrary to the anticipated results, this is the smallest group of terms (8% of the total instrument) and the discrepancy has little effect upon the total results obtained by the use of the instrument. One might suggest some rather speculative reasons for the teachers apparently being less well informed about these terms than the college students, but the usefulness of such speculations is highly questionable.

TABLE 3. Percentage of Individuals in Three Populations Responding to Philosophy and Ethics Terms.

Terms	*Never Heard Don't Know*	*Lowest Response*	*Medium Response*	*Highest Response*
Naturalistic				
H.S. Sophomores and Juniors	34%	58%	5%	3%
College Freshmen	33	42	8	17
H.S. Science Teachers	31	46	18	5
Morals				
H.S. Sophomores and Juniors	3%	54%	14%	30%
College Freshmen	8	50	25	17
H.S. Science Teachers	3	42	8	47
Truth				
H.S. Sophomores and Juniors	0%	11%	79%	11%
College Freshmen	0	25	75	0
H.S. Science Teachers	5	18	38	38
Normative				
H.S. Sophomores and Juniors	72%	14%	8%	6%
College Freshmen	33	33	17	17
H.S. Science Teachers	16	32	8	45
Teleological				
H.S. Sophomores and Juniors	84%	3%	3%	11%
College Freshmen	67	8	25	0
H.S. Science Teachers	46	15	10	28
Euthanasia				
H.S. Sophomores and Juniors	66%	11%	5%	18%
College Freshmen	42	17	8	33
H.S. Science Teachers	5	38	15	41

TABLE 4. Percentage of Individuals in Three Populations Responding to Reproductive Physiology Terms.

Terms	*Never Heard Don't Know*	*Lowest Response*	*Medium Response*	*Highest Response*
Tubal Ligation				
H.S. Sophomores and Juniors	50%	5%	24%	21%
College Freshmen	8	25	0	67
H.S. Science Teachers	13	5	23	59
AID				
H.S. Sophomores and Juniors	19%	57%	14%	11%
College Freshmen	33	25	8	33
H.S. Science Teachers	5	36	18	41
In Vitro Fertilization				
H.S. Sophomores and Juniors	76%	11%	5%	8%
College Freshmen	67	17	17	0
H.S. Science Teachers	5	13	49	33
Abortion				
H.S. Sophomores and Juniors	3%	45%	24%	29%
College Freshmen	17	25	17	42
H.S. Science Teachers	3	26	13	59
Diaphragm				
H.S. Sophomores and Juniors	21%	29%	32%	18%
College Freshmen	25	25	25	25
H.S. Science Teachers	0	29	34	37

Summary and Conclusions

Our assumption that one can develop a reliable concept level assessment instrument by using the method employed by the authors appears to be valid and is supported by the field test data. However, we are convinced that the key to using this instrument successfully hinges upon the respondents' understanding and following the instructions given at the beginning of the assessment instrument. If, for any reason, a respondent fails to complete the instrument exactly as instructed, the results could be totally invalidated. Willingness to cooperate and honesty in responding are absolutely essential to obtaining meaningful results. If administered properly and completed conscientiously, the CBCAI can be of use to an instructor in several different ways.

First, the instrument can identify for an instructor the concept terms with which the students are familiar and those terms to which the students have had little or no exposure. Also, the instructor can determine if an individual word is particularly unfamiliar to students. For instance, the term, "Hardy-Weinberg Equilibrium," received a 100% "don't know" response from the high school students. Therefore, when studying human genetics, the high school instructor could choose to spend more time discussing the Hardy Weinberg Equilibrium than a term such as "sex linkage," which received only a 41% "don't know" response from the high school students.

Second, it is possible to tell how well developed a given student's concept is of a particular bioethical or biological term. Using the comparison of high school students with high school teachers and using the term "abortion" as an example, the results show that 45% of the high school students chose the lowest concept level response as the one closest to their own definition; in comparison, 29% of the same group chose the highest concept level response. On the other hand, 59% of the teachers chose the highest concept level response as the one closest to their own definition, but only 26% chose the low concept level response. A teacher who is conscious of such concept differences will be better prepared to meet students at their own levels of understanding.

From results such as these, instructors can derive two benefits. First, instructors can use this information to concentrate their instruction on identified needs areas. Second, after retesting with the instrument at the end of instruction, teachers can evaluate how successful they were in raising the students' concept levels for the specific terms used in the instrument.

We are now using the validated CBCAI to assess entry and exit concept levels of students in courses at Ball State University. Data collected by use of the instrument have allowed us to adjust our instruction to the entry level of the students and to assess the effectiveness of teaching with respect to raising concept levels of students. We are convinced that teachers desiring to assess their students'

TABLE 5. Percentage of Individuals in Three Populations Responding to Human Behavioral Control Terms.

Terms	Never Heard Don't Know	Lowest Response	Medium Response	Highest Response
Biofeedback				
H.S. Sophomores and Juniors	37%	18%	26%	18%
College Freshmen	25	8	50	17
H.S. Science Teachers	8	32	34	26
Conditioning				
H.S. Sophomores and Juniors	59%	14%	14%	14%
College Freshmen	17	8	8	58
H.S. Science Teachers	3	36	8	54
Behavior Modification				
H.S. Sophomores and Juniors	29%	37%	13%	21%
College Freshmen	17	50	8	25
H.S. Science Teachers	3	39	37	21
Psychosurgery				
H.S. Sophomores and Juniors	39%	45%	5%	11%
College Freshmen	42	17	17	25
H.S. Science Teachers	39	26	18	16

entry and exit concept levels for objectives in their own courses could follow the methodology described in this article to design their own cognitive concept assessment instrument.

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