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Abstract: Describes the use of concept mapping (CM) in design, instruction and assessment, related to a microbiology program prepared for high school students in Israel. How CM was used in developing an hierarchically sequenced program; Information about the study and its objectives; How the impact of the program on students' achievements determined; Summary and discussion of the study.

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A COMPREHENSIVE USE OF CONCEPT MAPPING IN DESIGN INSTRUCTION AND ASSESSMENT

ABSTRACT

This study describes the use of concept mapping (CM) in design, instruction and assessment, related to a microbiology program prepared for high school (grades 10 and 11) students in Israel. It describes how CM was used in developing an hierarchically sequenced program. The impact of the new program on students' achievements was determined by comparing two groups: (a) students who studied the new program using CM themselves (mappers); and (b) students who studied the new program without CM. It was found that CM students' overall gain was higher. Students' and teachers' attitudes towards mapping were mostly favourable towards the cognitive benefits of CM. However, many students did not like certain aspects of CM. Some teachers exploit the potential of CM better than others.

Literature Review

Ausubel's learning theory (Ausubel, 1968; Ausubel et al., 1978) is based on the assumption that human thinking involves understanding concepts as well as the relationships among them. One of the important distinctions in Ausubel's theory is between rote and meaningful learning. When learning meaningfully, the learner links new, specialized concepts to more generalized concepts, which form the learner's cognitive structure. This linking process is designated as subsumption.

Two processes, namely `progressive differentiation' and `integrative reconciliation' of concepts, play an important role in meaningful learning (for further clarification of these terms, see below). Novak further suggests that concepts accompanied by propositions describing logical connections among them, are fundamental components of the cognitive structure. Consequently, the use of concept maps which reflect the concepts and their relationships was introduced (Novak, 1979).

Concept mapping is a process that involves the identification of concepts in study materials and their oganization from the most to the least general, more specific concepts (Novak, 1981, p. 3). Concept maps (CM) have been used as a tool for assessing meaningful learning (e.g. Novak, 1979), as well as in curriculum planning, instruction and evaluation (e.g Stewart et al., 1979). Research shows that concept mapping helps in gaining better and more comprehensive understanding of the learning material (Gurley, 1982). Students who construct their own maps organize the learning material so that it becomes more meaningful (Lehman et al., 1985). CM helps in revealing misconceptions and in identifying areas not fully understood (Fisher & Lipson, 1986; Feldsine, 1987; Fraser & Edwards, 1985). It was also found that most students, following some guidance, are capable of preparing CM Johnstone & Reid, 1981; Arnaudin et al., 1984).

Concept maps were used in teaching earth science (Ault, 1985), mathematics (Malone & Dekker, 1984), physics (Moriera, 1978; Watts, 1988; Pearson & Hughes, 1986a,b), statistics (Rogan, 1988), and biology (Novak, 1979; Stewart et al., 1979; Novak & Symington, 1982; Gurley, 1982; Novak et al., 1983; Arnaudin et al., 1984; Barenholz & Tamir, 1987; Staver & Bay, 1989). Research on students' attitudes towards CM showed differences among different learners, concerning their emotions and their thoughts about concept mapping and their contribution to learning (Arnaudin et al. 1984).

Up to this date there is no conclusive evidence that employing CM during the learning process, would result in higher grades in conventional achievement tests (e.g. Lehman et al., 1985; Rogan, 1988; Wandersee, 1988). Ault (1985) predicts that students that were used to rote learning, and gained satisfactory results in examinations, won't be interested in changing their learning habits by trying to deepen their understanding. As suggested by Novak & Gowin (1984) and by Rogan (1988), the influence of concept mapping on learning outcomes needs to be further investigated.

Purpose of Study

The present study was designed to examine the effect of a comprehensive use of concept mapping in the design, learning process and evaluation of a highschool microbiology course. More specifically the objectives of this study were:

(1) to describe how concept mapping was used in the program development;

(2) to describe how concept mapping was used in instruction;

(3) to examine the effect of concept mapping on students' achievement;

(4) to find out the students' and teachers' attitudes towards the new program and towards concept mapping.

Design of Study

Sample

The study involved high school students in the years 1983-1987. Subjects were chosen according to the following criteria:

(1) Students representing various types of schools and located all over the country;

(2) Students who had studied a basic cell biology unit;

(3) Students whose teachers were planning to teach microbiology and were interested in adopting the new program.

The study of biology in the 10th grade is compulsory, while in the 11th grade, biology is an elective course chosen only by students who plan to take the biology matriculation examination. Microbiology might be taught, according to teachers' choice, in either of these levels.

The 19 teachers who took part in this study, had a Bachelor or Masters degree, and 3-10 years of teaching experience.

Program Development

The choice of microbiology was made following a survey of learning materials in biology, available in

Israel in 1981, which revealed the need for an updated program in this area. To meet this need a new book, Chapters in Microbiology was written (Barenholz, 1985). A teachers' guide (Barenholz, 1989) and a laboratory manual were published in 1989 and 1990, respectively. The microbiology program includes the topics required by the national high school syllabus. Figure 1 shows how updated scientific knowledge and learning theory have been integrated in the new program.

The main features of this program which are congruent with Ausubel's learning theory are as follows:

(1) Sequential organization following the `principle of progressive differentiation' was used, i.e. the most general and inclusive ideas of the discipline are presented first, and are then progressively differentiated in terms of detail and specificity. For example, in the first chapter the sequence starts at a very general level, introducing the main themes of microbiology, namely, the wide distribution of micro-organisms, their essential hole in nature and their importance to Man, especially in food production and in relation to health. Each theme is developed later again by progressive differentiation in subsequent chapters. Concept maps are part of the program; maps are included in the text representing the main ideas, and, in addition, construction of concept maps is a regular course assignment. Figure 2 presents a concept map designed by a student who completed the study of the first chapter.

(2) Progressive differentiation takes place when similarities and differences between new and related existing concepts of higher generalization are pointed out. Subsumption occurs when new specific concepts are connected to more comprehensive concepts in the learner's cognitive structure. For example, the concept of `cell', a general concept which is familiar to the students who studied a basic cell biology unit, serves as `subsuming concept' to the new concepts, `eucaryotic cell' and `procaryotic cell'.

(3) A major strategy advocated by Ausubel to bridge the gap between what the learner already knows and what he needs to know before he can meaningfully learn the new information, is the use of an `advance organizer'. The first chapter, which presents a general preview and overview of microbiology, serves as an advance organizer for the study of the topics presented in subsequent chapters.

(4) The emphasis on concept learning is featured by defining and explaining main concepts in the text, by the inclusion of a glossary, as well as by students' assignments involving concept mapping.

The program was developed in three main phases: pilot, formative and summative. It was taught in grades 10 and 11. The background of students in the two levels varied, due to the structure of the Israeli school system. In the 10th grade all students have to take biology, while in grade 11 biology is taken only by students who elected to study it. The time required to complete the program was about 6 months. At each phase a part of the program was prepared, implemented in the classroom, revised and further developed, on the basis of: observations in the classroom, students' tests, and students' and teachers' attitudes towards the program and towards concept mapping. Following the completion of the students' text, a teachers' guide was prepared taking account of the results obtained in the study (Barenholz, 1989).

The Use of Concept Maps in Each Phase of Development

All the participating students designed concept maps during the first two phases. During the summative phase two groups were compared, namely, `mappers' and `non-mappers'. The mappers studied the new program with concept mapping as part of their assignments, whereas the non-mappers studied it without mapping, carrying out conventional assignments such as open ended questions. The mode of introducing concept mapping varied in the three phases. At the pilot phase, an example of a CM was presented to `mappers' and they had to prepare a concept map from a list of about 10 concepts. Most of the students prepared reasonable maps. For all students participating in this study, this was their first exposure to concept maps. At the formative phase, an exercise similar to the one reported by Gurley (1982) was carried out prior to concept mapping. Then the students prepared their own maps out of a given concept list. Most of the students prepared well designed maps.

At the two phases described above, a researcher was present while the mapping exercises took place. At the summative phase the students designed concept maps according to instructions included in the student text, without the presence of a researcher. Concept mapping was introduced only to the `mappers'. For most mapping assignments a concept list was provided, from which maps were drawn. Maps were also drawn by students after reading of a paragraph, a chapter or an article. Usually, one or two mapping assignments were required during or after studying each chapter. In two cases students were given complete maps integrated in the program, which they had to summarize in words.

The Use of Concept Maps in Assessment

Maps were also used as an evaluation tool. This evaluation had two main purposes.

(1) Maps were used for the program's evaluation, at each phase of the study. For example, in several students' maps during the pilot, one of microbiology's main principles (Koch's postulates) was wrongly presented. Consequently, the explanation of this principle was rewritten and the problem has been eliminated.

(2) Mapping was also part of the achievement tests and helped in assessing students' understanding.

During the pilot and formative phases all students' CM were evaluated. At the summative phase only a sample of maps was evaluated. As one of the tasks in the final examination, students were required to make a summing up map, including 20-30 concepts (see Fig. 2 for an example). In scoring the maps three criteria suggested by Novak & Gowin's (1984) were used, namely the number of concepts and propositions, the hierarchy and the branching (pp. 93-100). In addition, the quality of the propositions, the built hierarchy and the clusters of concepts, were assessed by subjective impression. Altogether 4 criteria were used (see Fig. 3).

The Effect of Mapping

Instruments

A variety of data sources was used in addition to the concept maps the use of which has been just described.

Achievement tests. These include (a) multiple choice questions, taken from the matriculation examination which were designed and validated by a committee of experts; (b) justifications to some answers (Tamir, 1989); (c) open-ended questions; (d) concept definitions; and (e) Self Report Knowledge Inventory (SRKI). The SRKI is less known than the other four instruments. It presents a list of concepts and respondents are asked to estimate their level of knowledge and understanding of each concept on a 5-point scale: 1 = I don't know; 2 = understand partially; 3 = know; 4 = understand well; 5 = can explain to a friend (for more details see Young & Tamir, 1977; Tamir & Amir, 1981).

Attitude inventories. Students' attitudes towards concept mapping, and towards the new program were identified by responses to an attitude questionnaire (see also Arnaudin et al., 1984) and through their comments (see examples below). Teachers' attitudes towards mapping and towards the new program were extracted from their comments.

The achievement of the two student groups that studied the program at the summative phase, was compared: (a) `Mappers' (N = 218) who performed concept mapping as a regular learning activity during the study of the new program; (b) `Non-mappers' (N = 98) who studied the new program without concept mapping.

Data analysis was carried out using SPSS program. Means and standard deviations were calculated and analysis of convariance was employed to compare the gain of the two groups.

The responses to the SRKI, which included 35 items, were submitted to varimax factor analysis. Seven subtests were formed on the basis of the results (see Table I).

Two measures were used to estimate the progress made during the study period, gain and gain of possible gain. Gain was obtained by subtracting the pretest from the post-test score. Percentage gain of possible gain was obtained by dividing the gain by the difference between the pre-test score and

100. The use of gain of possible gain rather than a simple gain was introduced by Thiele (1938) to overcome the ceiling effect. let us take for example two students who each gained 10 points from pre-test to post-test. The pre-test score of the first student was 70 and that of the second was 40. Was their gain identical? Thiele suggests that the answer is `No'. The first student had an opportunity to gain 30 points, so he has gained 33% of the possible gain. The second student has gained 10 out of possible 60 points so his gain of possible gain is only 17%. (In a sense the gain of possible gain is getting an effect similar to that obtained by analysis of covariance when the pretest score is the covariate.)

Effect size was calculated in order to estimate the educational significance of differences. Effect size (d) is obtained by subtracting the smaller mean score from the larger and dividing the product by the standard deviation of the control group (Glass et al., 1981). It is commonly accepted that: d < 0.2 standard deviation means no effect; d = 0.2 - 0.4 SD implies small effect; d = 0.4 - 0.6 SD medium effect; d=0.6-0.8 SD large effect; d > 0.9 very large effect (Cohen, 1969).

The raw scores obtained from the responses to different scales were transformed to a 100-point scale so that it would be easy to compare the scores of the different tests.

Validity arid Reliability

The validity of the instruments was established by a panel of four science educators and by the teachers who taught the program. Alpha Cronbach reliability for SRKI was 0 89 in the pre-test and 0 93 in the post-test. Alpha Cronbach reliability of the attitude inventory was 0 82. The Kuder Richardson reliability of the multiple choice test (17 items) was 0 78. The reliability of the remaining instruments was estimated by inter-rater agreement. In all cases the percentage of agreement exceeded 80%.

Results

The Impact of the New Program

Table I presents the results of the pre- and the post-tests, of all the students who studied the new program, regardless of whether they were mappers or non-mappers.

Considering gain of possible gain it may be seen that the highest progress was made in the SRKI in general microbiology, medical microbiology and types of cells; in the concept definitions in the topics antibiotics and types of cells; and in the topics of the two open-ended questions. The mean gain for these seven topics was 58% compared with 13% for the eight remaining topics. A close examination has shown that all the former topics are especially emphasized in the new program, while the others are not. This may be an indicator of the effect of the program.

The Results of Grade 10

In Table II the post-test scores of the two treatment groups in grade 10, are compared.

Table II reveals that according to post-test results, and effect sizes, the 10th grade mappers scored higher or equal to the non-mappers in most of the items. The difference was statistically significant in the SRKI sub-tests classification, cell biology, ecology and general microbiology. Mappers also scored significantly higher than non-mappers in justifying the correct answer on Inflammation, and in the definition of cell. Apparently understanding of these concepts was enhanced by concept mapping.

The Results of Grade 11

In Table III post-test results of the two treatment groups in grade 11, are compared.

From Table III it can be seen that in the 11th grade both groups did over all quite well and had similar results in several test items. In the SRKI, mappers scored significantly higher in general microbiology in classification and in distinguishing between different types of cells, whereas non-mappers scored higher in cell biology. Mappers scored substantially higher than non-mappers in the multiple choice questions, and in three of the definitions, namely, procaryotic-eucaryotic, antibiotics and antibody.

There were no other statistically significant differences. It is worth noting that higher achievement of mappers occurred in both grade levels in understanding general microbiology, classification and in defining procaryotic and eucaryotic-all emphasized in the program. There were six statistically significant differences in each grade level. However, in grade 10 three related to biological topics not included in the program (cell biology, ecology) whereas in grade 11 all were in topics covered by the program in microbiology. This implies that the impact of the program was greater in grade 11.

Students were also required to sum up the microbiology course in the final examination, either as a mapping assignment (by mappers) or as a written overview (by non-mappers). Mappers' instructions were: "Choose 20-25 concepts, that you consider as key concepts of microbiology, write them down, and use them to construct a map that will sum up what you consider as the most important topic you studied in the course". Non-mappers instructions were: "Choose 20-25 concepts that you consider as key concepts of microbiology, write them down, and use them in a written essay that will sum up what you consider as the most important ideas and principles you studied in the course". The mean score of maps (N = 197) was 66.8% (SD = 0.98), while the mean score of written essay (N = 92) was 65.3% (SD = 1.63).

Students' Attitudes towards Concept Mapping

At the end of the microbiology course mappers' attitudes towards concept mapping were evaluated. Ten questions (based on Arnaudin et al., 1984) were included (see Table IV). Only 206 students completed the attitude questionnaire. However, the students who did not respond to this questionnaire did not differ in their cognitive achievements from the rest. Hence, the responses of 206 may be generalized to the whole population.

We considered in our analysis mean scores less than 1.50 as not at all, 1.50-2.00 as very little, 2.01-2.50 as moderate and 2.51-3.00 as very much. Based on these criteria the following conclusions can be drawn. Students find mapping as quite a difficult task. Only a small proportion of the population thinks that mapping is a waste of time. To a moderate degree students think that mapping suits biology studies, does help in organizing complex learning material and is reflecting students' understanding of particular learning areas. Most students felt that mapping was not enjoyable. Most students are neither interested in discussing their maps with fellow students, nor in having teachers presenting maps in future classes.

Students were also asked to add their comments, and say what they thought and felt about concepts maps; 103 students responded to this request. Their comments were categorized into four typical patterns as follows (sample examples are added).

(1) I don't like mapping (11%): "I find mapping is a complex task, and I don't like doing it".

(2) Mapping is very helpful for microbiology study (25%): "The concept maps shown in the textbook, and those I prepared myself helped me in understanding better the learning material in microbiology".

(3) It is only moderately helpful to my studies (12%): "I think maps help you only to organize concepts and the relationship among concepts, no more".

(4) Mapping is especially helpful in organizing complex learning materials (52%): "In the study of biology CM help understand concept meaning and the relationship between different concepts and topics". "I think CM helps organize and remember things, clearly, and later helps develop new ideas".

Students' Attitudes towards the New Program

At the end of the microbiology course students' attitudes towards the new program were evaluated. using the same strategy as in the previous section. We shall refer only to those answers which are relevant to this paper. The answer to the question "to what extent was the presentation of the learning material clear and easy to understand" received a mean score "very much" (Multiple line equation(s) cannot be represented in ASCII text) "The learning material helped me deepen my concepts in biology" was rated "moderately" (Multiple line equation(s) cannot be represented in ASCII text). And "I learned many new concepts in microbiology" was rated "very much" (Multiple line equation(s) cannot be represented in ASCII text). Students were also asked to add their comments about the new program. Two-hundred-and-seventy-six students responded to this request. More than half of the students said that they liked the book and the style of presentation. Fifteen per cent said that they disliked mapping.

Teachers' Attitudes towards Concept Mapping

Teachers who taught with the aid of concept maps (at the summative phase), were questioned like the students about their attitudes towards concept mapping. Six teachers responded. Most of them had positive responses: mapping is helpful to most students (four teachers); it helps in comprehending concepts and in understanding the relationships among them (five teachers); mapping reflect students' understanding of a subject they were required to map (five teachers); it is helpful in revealing difficulties in concept understanding (four teachers); mapping is not a waste of time (five teachers); it is not difficult to learn for most of their students (three teachers).

Two out of the six teachers who answered these questions were especially favourable towards concept maps. This was reflected by the following examples: one teacher used maps herself in planning an ecology course and students (not taking part in our research) who studied a genetics course with her got mapping assignments. The other teacher, during the microbiology course, gave more mapping assignments than required in our program and her students were required to map a scientific research article they had to read. Teachers were also asked to assess the program. Eight teachers responded to this request. Examples of their comments are:

It is well organized and easy to understand.

I liked the hierarchy in which the material is organized.

Fifteen per cent said they disliked the mapping, 10% said that they disliked certain subjects in the program (eg. classification).

Summary and Discussion

In this study a whole learning program was developed, following Ausubel's and Novak's learning theory (Ausubel 1968; Ausubel et al., 1978). Following Novak's suggestions concept maps were integrated in all stages, namely, planning, development, instruction and students' assessment. Cognitive achievements as well as the attitudes of students towards the new way of learning were explored. Cognitive achievements were tested using a variety of approaches.

The main findings of this study were: Most of the students could perform concept mapping successfully by themselves or with little help from the teacher. Overall students who studied the new program scored in the post-test significantly higher than in the pre-test. 1 he mean percentage gain of possible gain was 30. When six topics which are emphasized in the program are considered separately, the gain amounts to 58%. The highest gains were in the topics general microbiology, medical microbiology, types of cells, antibiotics, antibody, food preservation and the importance of micro-organisms. The topics mentioned above are especially emphasized in the new program, and mapping procedures were employed while preparing the chapters dealing with them. Some of the other topics, of which gain of possible gain was lower, either dealt with general biology issues that were learnt previously or were less emphasized in the program textbook (some of these issues are dealt with in more detail in the laboratory guide, which was not included in the study).

Learning outcomes of mappers were either higher or equivalent, to those of non-mappers, except for very few cases. In none of these few cases was the difference statistically significant.

The effect of concept mapping on cognitive achievement in grade 10 was less related to the microbiology course than in the 11th grade. The mean effect sizes of the 20 measures included in Tables II and III were 0.27 and 0.32, respectively. Both results indicate that concept mapping was somewhat more effective in grade 11 than in grade 10.

Students' attitude towards mapping is somewhat complex. Most students find mapping a moderately difficult task to master and agree that mapping is not a waste of time. Most of the population agree on the cognitive value of mapping as an aid to meaningful learning and 52% state that it helps in organizing complex learning material. Yet 11% state that they don't like mapping and 12% say that it is only moderately helpful. In spite of the appreciation regarding the cognitive aspects, most of the mappers are not interested in sharing this experience by discussing their maps with their peers. These findings are similar to those of Gurley (1982) and Arnaudin et al. (1984). A possible explanation might be that the students don't appreciate the extra work required and they are not ready to change their already established learning habits. Starting mapping at a much earlier age might help in turning mapping activity into a routine assignment, so the students would not regard it as extra work, and will be more ready to share their experience with each other.

Most teachers in our sample showed a positive attitude towards concept mapping, and at least two were so enthusiastic that they used concept maps in different ways beyond the course. Since this course in microbiology was developed, a few in-service training courses in concept mapping have taken place, and the strategy is spreading among biography teachers.

TABLE I. Mean pre-and post-test scores for students who studied the new program (N = 190-230)

	Pre-test		Post-test	
Tests/sub-tests	X	SD	X	SD
SRKI sub-tests				
Cell biology	73.9	16.3	76.6	15.4
General biology	71.6	19.4	76.6	17.3
Medical microbiology	64.3	14.2	87.9	11.4
Ecology	63.7	20.7	76.0	18.2
General microbiology	57.3	25.4	86.3	17.7
Classification	40.8	13.0	64.0	19.2
Types of cells	32.8	23.7	77.8	23.8
Multiple choice(a)	37.3	24.0	56.4	34.0
Open-ended questions				
Food preservation	53.2	15.1	73.0	14.1
Importance of bacteria	59.8	16.8	81.9	15.8
Concept definitions				
Micro-organism	77.7	17.8	84.2	14.1
Cell biology	63.8	17.6	73.3	23.4
Antibody	55.8	22.7	82.9	19.5
Antibiotics	51.4	24.5	83.6	27.0
Types of cells	64.3	32.6	82.1	28.5

Tests/sub-tests	t	Gain	Percentage gain of possible gain
SRKI sub-tests			
Cell biology	2.62[**]	2.7	10
General biology	3.66[***]	5.0	18
Medical microbiology	21.85[***]	23.6	66
Ecology	9.19[***]	12.3	34
General microbiology	17.28[***]	29.0	68
Classification	14.81[***]	23.2	39
Types of cells	22.65[***]	45.0	67
Multiple choice(a)	11.92[***]	19.6	31
Open-ended questions			

Food preservation	12.42[***]	19.8	42
Importance of bacteria	11.36[***]	21.9	54
Concept definitions			
Micro-organism	4.10[***]	6.5	29
Cell biology	5.12[***]	9.5	26
Antibody	14.00[***]	27.1	48
Antibiotics	12.31[***]	32.2	66
Types of cells	3.57[***]	17.8	50

[**]P<0.01; [***]P<0.001. The number of students who responded to each item varied.

[a]For the multiple choice: N = 411.

TABLE II. Achievement of 10th grade mappers, non-mappers and comparison in the post-tests

Legends for Table:

A - Mappers N = 122-135
B - Non-mappers N = 30-45

	A		B		
Tests/sub-tests	x	SD	x	SD	t
SRKI sub-tests					
Cell biology	76.8	14.3	67.9	18.3	2.73[**]
General Biology	87.7	16.9	85.1	15.7	0.92
Medical microbiology	88.2	11.6	85.5	14.3	1.08
General microbiology	78.8	17.0	69.9	21.9	2.28[*]
Ecology	74.6	17.1	65.8	19.7	2.53[*]
Classification	57.0	15.3	45.4	16.7	3.42[***]
Types of cells	75.1	24.6	72.3	26.2	0.73
Multiple choice	53.6	32.5	53.7	25.9	0.04
Open-ended questions					
Food preservation	72.4	16.0	70.7	11.2	0.63
Importance of micro	80.1	16.6	78.2	15.4	0.65
Concept definitions					
Micro-organisms	81.0	14.9	82.5	21.3	0.43
Cell	64.2	22.4	51.2	9.8	4.27[***]
Procaryotic-eucaryotic	77.6	32.9	77.3	32.1	0.05
Antibodies	81.6	20.7	80.5	24.7	0.49
Antibiotics	82.4	28.6	84.4	21.7	1.20

Justifications					
Inflammation	61.3	29.7	41.3	26.0	3.16[**]
Immunity	76.5	16.8	74.4	10.0	0.98
Sterilization	80.1	26.4	84.3	23.2	1.01
Resistance to antibiotic	61.2	23.3	66.2	17.7	1.20

Tests/sub-tests	Effect size
SRKI sub-tests	
Cell biology	0.49
General Biology	0.13
Medical microbiology	0.20
General microbiology	0.41
Ecology	0.45
Classification	0.69
Types of cells	0.13
Multiple choice	0.00
Open-ended questions	
Food preservation	0.15
Importance of micro	0.12
Concept definitions	
Micro-organisms	-0.07
Cell	1.25
Procaryotic-eucaryotic	0.00
Antibodies	0.04
Antibiotics	-0.28
Justifications	
Inflammation	0.77
Immunity	0.21
Sterilization	-0.18
Resistance to antibiotic	-0.28

[***] P < 0.001; [**] P< 0.01;[*]P< 0.05. Designates higher score to non-mappers. The number of students who responded to each item varied.

TABLE III. Achievement of mappers and non-mappers in grade 11 in the post-tests

Legend for Table:
A - Mappers N = 77-83
B - Non-mappers N = 36 - 53

	A		B		
Knowledge inventory tests/subtests	x	SD	x	SD	t
SRKI sub-tests					
Cell biology	77.8	15.3	83.0	13.9	1.94
General Biology	76.2	16.6	73.6	18.6	0.80
Medical microbiology	88.9	10.9	87.0	12.0	0.88
General microbiology	90.6	14.0	76.4	20.9	4.36[***]
Ecology	78.5	19.7	72.0	19.4	1.48[***]
Classification	76.6	16.2	63.6	19.2	3.52
Types of cells	85.9	17.9	79.8	22.0	1.68
Multiple choice	71.3	29.1	41.9	44.4	1.44[***]
Open-ended questions					
Food preservation	72.4	13.8	73.6	16.2	0.18
Importance of micro	87.8	14.2	83.8	13.2	1.25
Concept definitions					
Micro-organisms	86.7	14.3	83.2	18.3	1.20
Cell	81.5	20.0	80.8	20.2	0.20
Antibody	86.4	15.3	78.4	19.8	2.51[*]
Antibiotics	87.3	25.3	66.0	31.8	4.01[***]
Procaryotic-eucaryotic	84.4	24.6	46.6	26.5	8.19[***]
Justifications					
Inflammation	61.7	28.8	60.6	34.0	0.15
Immunity	77.6	13.3	75.0	15.8	0.76
Sterilization	86.6	13.0	77.9	29.4	1.47
Antibiotic	77.5	19.2	69.2	16.6	0.82

Resistance to antibiotic	82.6	21.1	79.2	20.0	0.80

Knowledge inventory tests/subtests	Effect size
SRKI sub-tests	
Cell biology	-0.37
General Biology	0.14
Medical microbiology	0.14
General microbiology	0.70
Ecology	0.34
Classification	0.68
Types of cells	0.28
Multiple choice	0.66
Open-ended questions	
Food preservation	-0.07
Importance of micro	0.30
Concept definitions	
Micro-organisms	0.19
Cell	0.03
Antibody	0.40
Antibiotics	0.70
Procaryotic-eucaryotic	1.43
Justifications	
Inflammation	0.03
Immunity	0.10
Sterilization	0.30
Antibiotic	0.20
Resistance to antibiotic	0.17

[***]P<0.001; [**]P<0.01; [*]P<0.05.

Note: The number of students who responded to each item varied.

TABLE IV. Students' attitude towards concept mapping (N=206)

Legend for Table:
A - (1) Not at all
B - (2) Moderately
C - (3) Very much
D - SD

Item	Distribution in percentages				
	A	B	C	x	D
Mapping suits biology studies	25	47	29	2.03	0.73
You intend to use mapping in various subjects	46	48	6	1.60	0.62
It is difficult to study mapping	36	50	14	1.77	0.68
Mapping is a waste of time	42	39	19	1.76	0.75
Maps you prepared do reflect your knowledge	18	47	35	2.18	0.70
Organizing material in maps help in concept understanding	22	40	38	216	0.77
Mapping helps in detecting unclear concepts	37	44	19	1.81	0.73
Mapping is pleasant	41	40	19	1.77	0.74
I like teachers to present maps	58	32	10	1.51	0.66
I like discussing my maps with friends	69	25	6	1.35	0.58

DIAGRAM: FIG. 1. A concept map representing the overall idea of the microbiology course designed within the framework of the study.

DIAGRAM: FIG. 2. Student's map summary of the first chapter in the textbook.

DIAGRAM: FIG. 3. A concept map, drawn by a student, on the topic of disease prevention. Scoring of the concept map: number of concepts. 9; quality of hierarchy, 6; overall impression, 8; total score, 32. Comments double use of `prevent'; `hygiene' is on top of the hierarchy; the distinction between prevention and detection is not clear.

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