# TEACHING MICROBIOLOGY TO UNDERGRADUATE STUDENTS IN THE HUMANITIES AND THE SOCIAL SCIENCES

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**Running title:** Teaching microbiology to humanities students

**One sentence summary:** A historical approach was successfully used to teach general microbiology to classes of undergraduate students in the humanities and social sciences lacking basic knowledge of biology and chemistry.

**Abstract**

This paper summarizes my experiences teaching a 28-hour course on the bacterial world for undergraduate students in the humanities and the social sciences at the Hebrew University of Jerusalem. This course was offered in the framework of a program in which students must obtain credit points for courses offered by other faculties to broaden their education. Most students had little biology in high school and had never been exposed to the basics of chemistry. Using a historical approach, highlighting the work of pioneers such as van Leeuwenhoek, Koch, Fleming, Pasteur, Winogradsky, and Woese, I covered a broad area of general, medical, environmental and evolutionary microbiology. The lectures included basic concepts in organic and inorganic chemistry necessary to understand the principles of fermentations and chemoautotrophy, and basic molecular biology to explain biotechnology using transgenic microorganisms and molecular phylogeny. Teaching the basics of microbiology to intelligent students lacking any background in the natural sciences was a rewarding experience. Some students complained that, in spite of my efforts, basic concepts of chemistry remained beyond their understanding. But overall the students' evaluation showed that the course had achieved its goal.

**Keywords**: General bacteriology; Medical microbiology; Social sciences; Humanities; Undergraduate studies; History of science

## INTRODUCTION

A few years ago the Hebrew University of Jerusalem established the ‘Cornerstone’ program to enrich the knowledge and thinking of its students outside their own discipline. Similar programs are offered by many of the leading universities in the world. The philosophy behind such programs is that university graduates should not only be trained in a particular academic specialty but also be broadly educated. The website of the ‘Cornerstone’ program (ap.huji.ac.il, most of which is in Hebrew) explains that the Hebrew University believes in the importance of general education, and that exposure to other disciplines now may be beneficial to the students in the future in ways that cannot be predicted today.

The program started on a small scale in 2009-2010. Following evaluation at the end of 2011-2012, implementation on a full scale was approved. Each undergraduate student of social sciences, natural sciences, and humanities must select courses equivalent to four semester-hours in each of the other two disciplines. Similar arrangements exist for faculties such as medicine and law. Most courses in the ‘Cornerstone’ program were established specially for the purpose, adapted to the background of the students, and they are offered on the campus where the students spend most of their time.

In 2014-2015, 143 courses were offered in the framework of the program: 62 the humanities, 57 in social sciences, and 24 presented by teachers of the faculty of mathematics and natural sciences. Courses in the life sciences field included “Introduction to modern biology”, “Sex and evolution”, “The degenerating brain: from research to hope”, “Rational drug design and discovery”, “Secrets of the human genome”, and others.

## A COURSE ABOUT THE BACTERIAL WORLD FOR STUDENTS IN THE HUMANITIES AND THE SOCIAL SCIENCES

Two years ago I volunteered to teach a 2 credit point course, fourteen 1.5-hour lectures, about the bacterial world in the framework of the ‘Cornerstone’ program. I have now taught this course twice for groups of around 100 undergraduate students majoring in sociology, linguistics, business administration, bible studies, history, archaeology, psychology, and other fields. Only a small part of the students had been exposed to life sciences during their high school years, and very few had learned basic chemistry. My challenge was thus to teach a course on an appropriate academic level to mostly bright students lacking a background in biology and without any knowledge of chemistry. The language of teaching was Hebrew, but the text on most slides of the PowerPoint presentations shown was in English, as customary in nearly all courses and seminars at our science faculty. These PowerPoint presentations were made available to registered students on the course website immediately after each lecture.

Non-biologists generally associate the term ‘bacteria’ first of all with nasty pathogens that have to be killed with antibiotics. Some students may therefore have expected that bacterial diseases will be the main topic of the course. Instead I attempted to provide a balanced view of the diverse world of the prokaryotes, including medical, environmental and industrial aspects, to show what bacteria are, how they function, and how they influence our daily lives for better or for worse. Table 1 presents a list of the lectures and the topics covered.

Each lecture started with historical aspects, highlighting one of the pioneers in the field (Table 1, Fig. 1), and taking the key discoveries and publications of the old masters as the starting point. Often the choice of the scientist featured was obvious: one cannot discuss bacterial pathogens without explaining Robert Koch’s work, or fermentations and anaerobic processes without going back to Pasteur. van Leeuwenhoek, Fleming, Winogradsky, Beijerinck and Woese were featured for similar reasons. In other cases I selected the scientist according to the topic of the lecture. For a presentation on endospore-forming bacteria I felt that Ferdinand Cohn’s 1876 study would make a suitable starting point, although Cohn devoted most of his career to other topics. I could have introduced Cohn also as a pioneer of prokaryote taxonomy, but as I had used him before, I selected David Bergey. I could have started the talk about motility by introducing Julius Adler, but Theodor Engelmann’s experiments performed 80 years earlier are so elegant that I preferred to show the earlier beautiful work.

Each talk featured a short biography of the scientist, based on information from a book on the history of microbiology (Schlegel 1999), monographs on the featured microbiologists (e.g. Dobell 1932; Waksman 1953; van Iterson *et al.* 1983) and internet sources. Presentations of the early work generally were based on the original papers, sometimes shown in their original language (e.g. Cohn 1876; Koch 1876; Engelmann 1883) or based on translations (Brock 1999). Two classic popular or semi-popular books, De Kruif’s *Microbe Hunters* (1926) for topics related to medical microbiology and Dixon’s *Power Unseen: How Microbes Rule the World* (1994), were very helpful during the preparation of the presentations. After the historical introduction each lecture continued with information about later developments and the current state of the art of the topic.

In spite of the fact that chemistry and physics are even more unfamiliar to these students than biology, teaching basic concepts from those disciplines was necessary to show the ways bacteria function. Therefore the course included explanations on Reynolds numbers (lecture #2), simple organic chemistry equations to explain the nature of fermentations (but without details about energy conservation as ATP) (lectures #8 and #9), DNA, RNA, and the genetic code (lecture #9), redox reactions in inorganic chemistry, a topic that tends to be difficult even for students majoring in biology) (lecture #11), and lipid structure (lecture # 14). The chemistry part was experienced by many as the most 'difficult' part of the course. But by using analogues from the macroscopic world it is often possible to explain the workings of the microorganisms. Thus, chemotaxis in bacteria, with flagella, the flagellar motor that needs energy, sensors to probe the environment, and a transduction mechanism to instruct the motor what to do, can be compared with the wheels, engine, fuel, and steering wheel of a car and the eyes and the brain of its driver.

I gratefully used the wealth of cartoons and other illustrations available in books and on the internet to enliven the presentations. Many of the cartoons shown were derived from *What's so Funny about Microbiology?* (Czichos 1987). Another appealing source of pictures is www.giantmicrobes.com, from a company that sells stuffed toys in the shape of disease-causing bacteria and viruses. For lecture #3 I brought a number of agar plates (well-sealed to avoid safety problems) to the classroom to show colonies of different shape and color that had developed after exposure to water, soil, fingerprints, or after opening the lid for a few hours to obtain a wealth of colonies of bacteria and fungi.

I also incorporated short movies available on YouTube and other internet resources to illustrate concepts presented:

In lecture #2 (bacterial motility): https://www.youtube.com/watch?v=Gpavfy9bIGY;
https://www.youtube.com/watch?v=4hexn-DtSt4;
https://www.youtube.com/watch?v=KEvJEgmIB3M;
http://www.haloarchaea.com/halo_motility.html.

In lecture #3 (bacterial cell division and colony formation):
https://www.youtube.com/watch?v=gEwzDydciWc.

In lecture #5 (leucocytes engulfing bacteria):
https://www.youtube.com/watch?v=JnlULOjUhSQ/

In lecture #9 (the basics of molecular biology, protein synthesis, and regulation of gene expression): https://www.youtube.com/watch?v=Ikq9AcBcohA;
http://www.youtube.com/watch?v=oBwtxdI1zvk

To prove that scientists are human beings who deal with other matters as well, I included many trivia from the lives of the pioneers featured in the talks. I showed (lecture #2) that Johannes Brahms had dedicated one of his string quartets to Theodor Engelmann, who (like the author of this essay) liked to dabble in music, how (lecture #11) Sergei Winogradsky had been a piano student at the St. Petersburg Conservatory and how he spent many years as a landowner-farmer, and how (lecture #12) Martinus Beijerinck, generally known as a person interested only in science and without any sense of humor, made fun of the long words that one can coin in the German language in a short article proudly describing his invention of the 'Kapillarhebermikroskopirtropfenflasche' also to be used as 'Kapillarheberbakterienkulturkölbchen' (Beijerinck 1891): a nice challenge for the aspiring linguists in the class.

I also like to refer to the local scientific scene in our country. Israel is unique as two out of the ten presidents that have served since the establishment of the state had been microbiologists/biotechnologists: Chaim Weizmann and Ephraim Katzir. Weizmann was also one of the founding fathers of our university. Therefore I started lecture #5, the talk about antibacterial drugs, with a little quiz, offering a bottle of wine to the student who will first give the correct answer. The question was: Who were the partners in the following conversation:

> "You have kept me nearly an hour. Do you know that out there, in the corridor, there are counts, princes and ministers who are waiting to see me, and who will be happy if I give them 10 minutes of my time?"
>
> "Yes, Professor ..., but the difference between me and your other visitors is that they come to receive an injection from you, and I came to give you one."

That conversation, as recorded in Weizmann's autobiography (Weizmann, 1949), took place in 1914 between Chaim Weizmann and Nobel laureate Paul Ehrlich who first developed antibacterial chemotherapy. It was a successful attempt by Weizmann to arouse enthusiasm for his idea to establish a university in Jerusalem. A few students correctly identified Weizmann, but nobody guessed Paul Ehrlich's name. The impact of Weizmann's microbiological studies is nicely shown in the title of Bernhard Dixon's essay "*Clostridium acetobutylicum* – creator of the state of Israel" (Dixon 1994).

Another local invention discussed (lecture #6) was the use of *Bacillus thuringiensis* var. *israelensis* to kill larvae of mosquitos and other insects (Goldberg and Margalit 1977).

Discussions on eukaryotic microorganisms were kept to a minimum: yeasts in bread and wine fermentation and their use in biotechnology for production of recombinant proteins.

Viruses were only briefly mentioned as disease agents and as useful tools in genetic engineering.

I do not know any textbook at the level of our students that can serve as background study material for the course. I mentioned *Brock Biology of Microorganisms* to those who want to read more, realizing that such a book requires a rather high level of knowledge in chemistry. Those wishing to learn more undoubtedly found their way to Wikipedia and other internet sources.

## GRADING

The course ended with an exam consisting of 25 multiple-choice questions, with one correct answer out of four or five possible options. Table 2 shows a few examples. Students who failed the exam or wanted to improve their grades had the opportunity of a do-over exam.

There was a great difference in the grades of the exam in the first year on the one hand and the subsequent do-over exam and the second year's exams on the other hand. Some statistics (average grade ± standard deviation (number of students, number of students with grades <60)): First year: 66.7 ± 14.9 (101, 24); first year, do-over exam: 87.6 ± 11.1 (63, 1); second year: 84.3 ± 15.8 (77, 9); second year, do-over exam: 81.1 ± 10.5 (40, 2). Students at our university have access to all previous exam questions: it is considered one of their basic rights. Unfortunately (at least, from the point of view of the teacher) this leads to a situation in which some students prefer studying old exams rather than the material taught in class. By doing so they may obtain a passing grade without the need to attend lectures. As the course was new, the first group of students did not know what to expect and they had no reference material from previous years.

## FEEDBACK FROM THE STUDENTS DURING THE COURSE

As attendance in the classroom was not obligatory, the number of students present at the lectures in the ~110-seat auditorium was to some extent a measure of their interest and involvement. Because of a technical error 142 students registered in the first year; in the second year there were 114 registered students. In the first year the lecture hall was generally 80-90% full, in the second year 70-80% throughout the semester.

I was positively surprised about the number of interesting questions asked during the lectures, showing true interest from the students and the wish to learn more. I liked the question (lecture #5) whether the mouthwash Listerine has anything to do with Joseph Lister (of course it has!). And I was thrilled when one of the students asked me by e-mail whether I was familiar with the British artist Luke Jerram who had crafted models of bacteria, bacteriophages and other viruses out of glass (http://www.lukejerram.com/glass) (I had never seen those beautiful creations, and I started the next lecture showing a selection to the class). In the second year I had one student, majoring in archaeology and biblical studies, with very broad interests, who had studied biology in high school at a surprisingly high level. He flooded me with interesting questions in class and also spent several hours in my office asking more questions and suggesting original (but not very practical!) ideas how to improve microbiological science.

There also was an interesting contribution from one of the ‘third age’ participants in the course. Each year the course was joined by a few pensioners who came to enrich their education. During lecture #4 I drew the parallel between the work of Robert Koch (Nobel Prize 1905) and Barry Marshall (Nobel Prize 2005) who by following Koch’s postulates had shown that gastric ulcers are caused by bacteria. The not-so-young ‘student’ explained to the class that he had recently been cured of his gastric ulcer following antibiotics treatment. He did not know about Marshall’s discovery before, and he was intrigued to learn that two decades earlier no physician would have thought about prescribing antibiotics to cure his ailment.

## COMPUTERIZED EVALUATION OF THE COURSE

During the last weeks of each semester, students of our university are invited to complete anonymous computerized evaluations of each of their courses. In both years about one third of the registered students in our course used the opportunity to provide feedback to the teachers and to the university authorities. This unfortunately low number is characteristic of the students’ participation in such course evaluations: students apparently prefer spending their time studying for the upcoming exams rather than sitting in front of their computer to express their opinion about their teachers.

The evaluation consisted of two parts:

(1) Grading the course contents and the teacher on a scale from 1 (poor) to 9 (excellent). Figure 2 summarizes these grades for the first and the second year.

(2) Text comments in three categories: (a) Positive aspects of the course; (b) Suggestions for improvement; (c) Comments related to the teacher. Below is a small selection of the more informative comments, translated from Hebrew, edited and shortened.

**Positive aspects of the course**

- Linking between biological information and the historical and cultural aspects during the periods discoveries were made was very useful. Very suitable for a course intended for students in the social sciences and humanities.
- The course provides basic information about the world of biology and chemistry at a level that every student, also without previous knowledge, can understand (*Not all students agreed*).
- The teacher nicely referred to processes and products known from our daily life … He did not make concessions when explaining topics he wanted us to understand, also when the material was more complicated.

**Suggestions for improvement**

Most of the less positive comments related to the chemical equations in some of the talks:

- In the beginning the material was ‘friendly’ and understandable but as the course progressed, the material started to be more complex. The chemistry lessons were complicated and not understood. I never studied chemistry/biology/physics, and unfortunately the course did not provide the tools to cope with such material.
- The teacher needs to reduce the amount of chemistry as much as possible; this is difficult for a large part of the class. (*I wish I knew how to teach microbiology without at least some chemistry*).

Further suggestions:

- The PowerPoint presentations were in English and that made it much more difficult (*English is the language of science and every student accepted to our university must show proficiency in English*).
- It would be nice to record the lectures on YouTube so that more students can take the course as the course coincides with required courses (*the possibility of recording the*

*classes was offered, but as I feel less comfortable when I know I am recorded I preferred not to use this option*).

**Comments related to the teacher**

- The teacher tried in each lecture to keep the students interested and motivated by combination of personal stories, simple concepts and explanations together with theoretical material at a high level.
- The comics added much to the atmosphere.
- He is very much aware that we do not major in natural sciences, and he tries to teach at a speed suitable for us.

## FINAL COMMENTS

Teaching a microbiology course for students in the humanities and the social sciences has been a rewarding experience. Preparing lectures with these students in mind has given me an entirely different perspective of our discipline. I intend to offer this course again in the coming years.

At the end of the last lecture one student told me: “You know, I even started dreaming about bacteria!” I hope that also in the future I will be able to convince our students that the bacterial world is fascinating, and not only for scientists and students of natural sciences and medicine.

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*Conflict of interest.* None declared.

## REFERENCES


Beijerinck MW. Die Kapillarhebermikroskopirtropfenflasche. *Centralbl Bakteriol Parasitenkd* 1891;**9**:589-90.

Brock TD. *Milestones in Microbiology. 1546 to 1940.* Washington, D.C. ASM Press, 1999.

Cohn F. Untersuchungen über Bakterien. IV. Beiträge zur Biologie der Bacillen. *Beiträge zur Biologie der Pflanzen* 1876;**2**:249-76.

Czichos J. *What's so Funny about Microbiology?* Madison, WI: Science Tech Publishers, 1987.

De Kruif P. *Microbe Hunters.* New York: Blue Ribbon Books, 1926.

Dixon B. *Power Unseen: How Microbes Rule the World.* Oxford: W.H. Freeman/Spektrum, 1994.

Dobell C. *Antony van Leeuwenhoek and his "Little Animals": Being some Account of the Father of Protozoology and Bacteriology and his Multifarious Discoveries in these Disciplines*. New York: Harcourt, Brace and Company, 1932.

Engelmann TW. *Bacterium photometricum*. Ein Beitrag zur vergleichenden Physiologie des Licht- und Farbsinnes. *Arch Physiol* 1883;**30**:95-124.

Goldberg LJ, Margalit J. A bacterial spore demonstrating rapid larvicidal activity against *Anopheles sergenii*, *Uranotaenia unguiculata*, *Culex univittatus*, *Aedes aegypti* and *Culex pipiens*. *Mosquito News* 1977;**37**:355-8.

Koch R. 1876. Die Ätiologie der Milzbrandkrankheit begründet auf die Enwicklungsgeschichte des Bacillus Anthracis. *Beiträge zur Biologie der Pflanzen* 1876;**2**:277-310.

Madigan MT, Martinko JM, Stahl DA, Clark DP. *Brock Biology of Microorganisms.* $13^{th}$ ed. Boston: Pearson, 2012.

Schlegel HG. *Geschichte der Mikrobiologie.* Halle (Saale): Deutsche Akademie der Naturforscher Leopoldina, 1999.

van Iterson G Jr, den Dooren de Jong LE, Kluyver AJ. *Martinus Willem Beijerinck. His Life and his Work.* Madison, WI: Science Tech, Inc., 1983.

Waksman SA. *Sergei N. Winogradsky. His Life and Work. The Story of a Great Bacteriologist.* New Brunswick: Rutgers University Press, 1953.

Weizmann C. *Trial and Error: The Autobiography of Chaim Weizmann.* New York: Harper & Bros., 1949.

**Table 1.** Outline of the 14-week course “The world of the bacteria” for undergraduate students in the humanities and the social sciences at the Hebrew University of Jerusalem, 2013-2014 and 2014-2015.

| Week | Title of the lecture | Topics covered |
|---|---|---|
| 1 | **Antonie van Leeuwenhoek and his little animalcules.** What are bacteria? Introduction to the world of prokaryotes. | General introduction to the course; what is microbiology; the life and work of Antonie van Leeuwenhoek; the development of microscopes; the sizes and shapes of bacteria; the electron microscope; eukaryotic and prokaryotic cells; anatomy of the bacterial cell; the bacterial cell wall and the Gram stain. |
| 2 | **Theodor Engelmann and phototaxis.** How bacteria move around in nature. | Motile bacteria; Theodor Engelmann’s chemotaxis and phototaxis experiments: use of aerobic bacteria to prove that chloroplasts produce oxygen; phototaxis in “Bacterium photometricum” (*Allochromatium vinosum*); anatomy of the bacterium flagellum and its motor; chemotaxis experiments using capillaries; how bacteria sense concentration gradients and move toward attractants; buoyancy regulation by gas vesicles. |
| 3 | **Lourens Baas Becking – "Everything is everywhere; but, the environment selects".** How many bacteria are there in water, soil, and air? | “Everything is everywhere; but, the environment selects”; the bacterial growth curve; growth rates and the limitations to exponential growth; cultivation of bacteria on solid media; enumeration of bacteria, bacterial numbers in water, soil, and in and on the human body; “the great plate count anomaly”; selective media and enrichment cultures; biogeography and dispersal of prokaryotes. |

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| 4 | **Robert Koch and his postulates.**<br>Isolation of bacteria in pure culture; pathogenic bacteria. | The scientific career of Robert Koch; which diseases are caused by bacteria?; development of pure culture techniques using solidified media; what do growth media contain? Koch's postulates: anthrax, tuberculosis, cholera; Koch's postulates today: the case of *Helicobacter pylori*. |
| 5 | **Alexander Fleming and penicillin.**<br>How to kill undesired bacteria? | Methods to kill bacteria; the autoclave; heat resistance of endospores; pasteurization vs. sterilization; detergents and other antiseptic agents; strategies of the human body to fight intruding bacteria; lysozyme; the immune system; chemotherapy: salvarsan and sulfa drugs; antibiotics: penicillin, streptomycin, and others; the mode of action of antibiotics; development of antibiotics-resistant bacteria; why are so few new antibiotics being developed in recent years? |
| 6 | **Ferdinand Cohn and endospore-forming bacteria.**<br>Tetanus, botox, insecticides, and more. | Long-time survival of endospores of *Bacillus* and *Clostridium*; how long can spores survive? anthrax, tetanus and botulism – the action of exotoxins; applications of endospore-forming bacteria: Botox, washing powder enzymes, *Bacillus thuringiensis* as an insecticide. |
| 7 | **David Bergey and bacterial nomenclature.**<br>How do we define species of bacteria and how many species do we know? | How many species and genera of prokaryotes have been described? How do we keep track of the number of prokaryotic species? Bergey's Manual; the International Committee on Systematics of Prokaryotes; the International Journal of Systematic and Evolutionary Microbiology and valid publication of names; classification of bacteria; criteria for the description of new species; rules for naming new species; Latin and Greek in biological nomenclature. |

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| 8 | **Louis Pasteur and his fermentation studies.**<br>On lactic acid, spoiled wine, and spontaneous generation. | The career of Louis Pasteur, highlighting two topics of his research: disproving spontaneous generation and life without oxygen; the principles of fermentation by bacteria and yeasts; ethanol fermentation; the microbiology of wine making; diseases of wine; lactic acid, propionic acid and other fermentations, explained using simple organic chemistry and energetic considerations; partial oxidation: the production of vinegar. |
| 9 | **Chaim Weizmann and acetone fermentation.**<br>Bacteria as factories for the production of chemicals. | Industrial fermentations and scaling up of production facilities; acetone production by *Clostridium acetobutylicum*; microbial production of citric acid, sodium glutamate, antibiotics, and enzymes for washing powders; poly-β-hydroxyalkanoates as biodegradable plastics; the principles of genetic engineering, brief introduction to molecular biology and the genetic code; recombinant DNA; use of microorganisms to produce medicines and other valuable compounds; ethical aspects of recombinant DNA work. |
| 10 | **Alessandro Volta and combustible air.**<br>Methane in marshes and in the ruminant stomach. | The Volta experiment to show production of flammable gas in marshes; methane formation by prokaryotes in marsh sediments and in digestive systems; the microbial community in the ruminant stomach and the mode of nutrition of ruminant animals; termites as methane producers; anaerobic sludge digestion in water purification plants. |
| 11 | **Sergei Winogradsky and the concept of chemoautotrophy.**<br>Inorganic compounds as energy sources. | The different energy sources for life; recognition of reduced inorganic compounds as energy sources; introduction to inorganic redox reactions; Winogradsky's studies on chemoautotrophic sulfur oxidation (*Beggiatoa*) and nitrification in the biogeochemical cycles of sulfur and nitrogen; nitrification; chemoautotrophy-based ecosystems in sulfidic caves and in deep-sea hydrothermal vents. |

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| 12 | **Martinus Beijerinck and nitrogen fixation.** The role of bacteria in the biogeochemical cycles. | The power of the enrichment culture principle; free-living and symbiotic nitrogen-fixing bacteria; anaerobic respiration: denitrification and dissimilatory sulfate reduction. The microbial nitrogen cycle; dissimilatory sulfate reduction and the sulfur cycle. Exploitation of different aerobic and anaerobic steps in the microbial cycles of carbon and nitrogen in water purification plants. |
| 13 | **Thomas Brock and the Yellowstone hot springs.** Bacteria in extreme environments. | Exploration of the limits of prokaryotic life; Life at high temperatures: hot springs and submarine hydrothermal vents; the upper temperature limit of life; life at low temperatures and at high hydrostatic pressure; life at low and high pH; adaptation of microorganism to high salt concentrations; halophilic life in solar salterns and in the Dead Sea. |
| 14 | **Carl Woese and the Archaea.** Evolution in the bacterial world. | Theories about the origin of life and the nature of the first prokaryotes; ‘molecular clocks’ to trace the evolution of life on earth; structure of the ribosome; use of small-subunit ribosomal RNA for reconstruction of early evolution; Archaea as the third lineage of life; how different are Archaea from other prokaryotes? |

**Table 2.** Examples of exam questions.

| **Question** | **Possible answers** | **Comments** |
|---|---|---|
| The Gram stain provides information about: | a. Presence of absence of peptidoglycan in the bacterial cell wall<br>b. The thickness of the peptidoglycan in the bacterial cell wall<br>c. Affiliation with the Archaea or with the Bacteria<br>d. The prokaryotic or eukaryotic nature of the cell | Correct answer: b |
| Agar, a product from certain marine algae, is commonly added to growth media for bacteria: | a. As a source of vitamins and minerals for growth<br>b. To inhibit growth of fungi<br>c. As a source of sugars used as energy source<br>d. To produce a solid medium on which bacteria develop colonies | Correct answer: d<br>The possibility that some marine bacteria may degrade agar was also discussed in class |
| Many washing powders contain enzymes produced by bacteria. Bacteria make such enzymes: | a. To break down large molecules such as proteins and starch and use these as a source of food<br>b. To kill viruses<br>c. To inhibit growth of fungi<br>d. To penetrate into animal cells and cause disease | Correct answer: a<br>Option b was added as the lecture on genetic engineering mentioned restriction enzymes |
| *Rhizobium* bacteria that live in | a. Nitrate produced from gaseous nitrogen | Correct answer: b |

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| symbiosis with leguminous plants contribute to the plant: | b. Ammonia produced from proteins<br>c. Ammonia produced from gaseous nitrogen<br>d. Nitrate produced from amino acids | An example of some simple inorganic and organic chemistry introduced during the course |
| Archaea are not sensitive to lysozyme as: | a. Archaeal cells lack a cell wall<br>b. The cell wall of Archaea does not contain peptidoglycan<br>c. The lipids of Archaea differ from the lipids of the Bacteria<br>d. The structure of the archaeal ribosome is different from the bacterial ribosome | Correct answer: b<br>Ether and ester lipids were discussed at the last lecture, peptidoglycan already during the first presentation |

## Legends to the Figures

**Figure 1.** The final page of the PowerPoint presentation of the closing lecture: portraits of microbiologists from the past and the present who featured as the starting point for the 14 lecture sessions in the course "The world of the bacteria" for students in the humanities and the social sciences taught at the Hebrew University of Jerusalem in 2013-2014 and 2014-2015: (top row) Antonie van Leeuwenhoek, Theodor Engelmann, Lourens Baas Becking, Robert Koch; (middle row) Martinus Beijerinck, Carl Woese, Thomas Brock, Ferdinand Cohn, Alexander Fleming; (bottom row) Sergei Winogradsky, Alessandro Volta, David Bergey, Louis Pasteur and Chaim Weizmann.

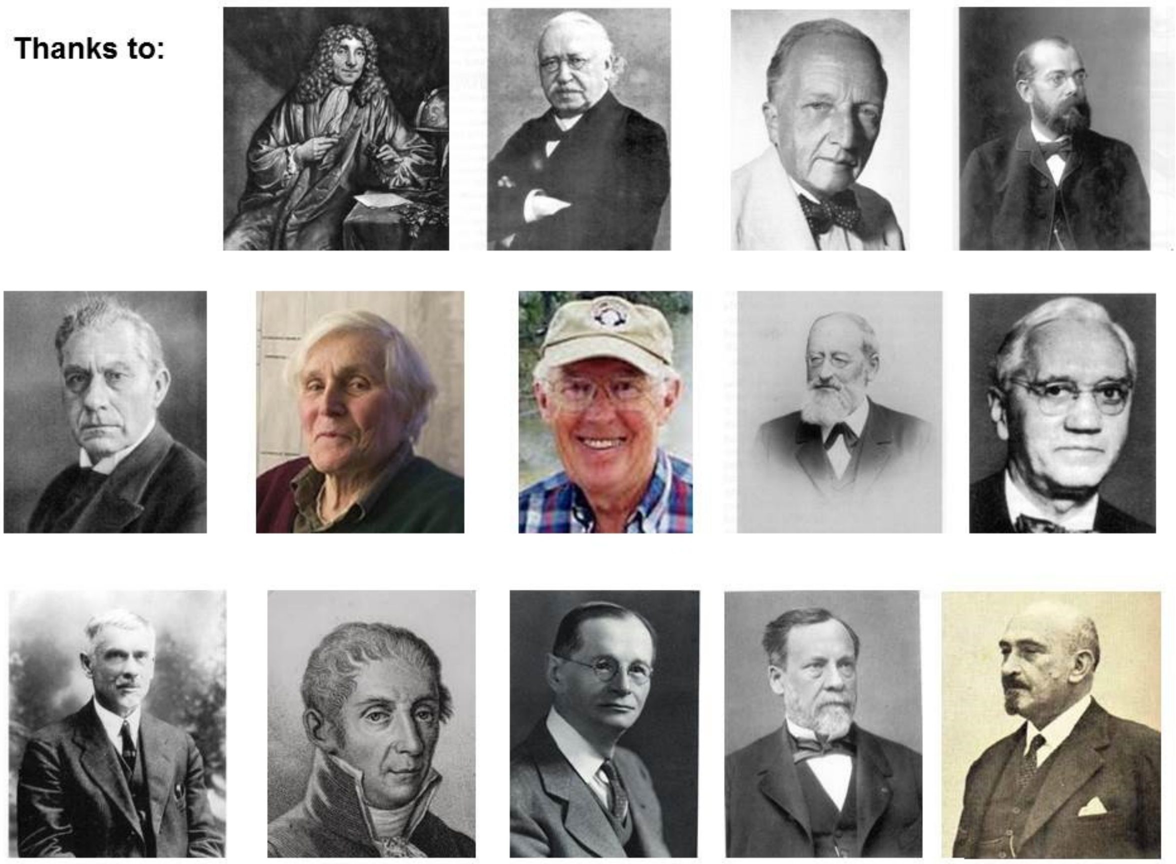

**Figure 2.** Summary of the students' evaluation of the content of the course and of the teacher (right panels) of the course "The world of the bacteria" (left panels) taught at the Hebrew University of Jerusalem for students in the humanities and social sciences in 2013-2014 (upper panels) and 2014-2015 (lower panels).