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Interdisciplinary Collaboration in Teaching Nanotechnology

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ABSTRACT: *During 2003-04, a new sophomore-level course was developed and taught – Introduction to Nanotechnology. Our new course was team-taught by faculty in the basic sciences, engineering and ethics, and it was oriented toward biological applications. The enrolled students were science and engineering majors. The course was facilitated by the materials science faculty member. The course focused on three applications: micro-arrays, micro-fluidics and nano-biomedical structures. The students were grouped into multidisciplinary teams for study groups and a class project. The examples of our assessment methods (both formative and summative) are in accordance with ABET's requirements.*

1 INTRODUCTION

Although many universities are conducting graduate-level research in nanotehcnology, few (if any) universities offer undergraduate courses in nanotechnolgy. Possibly, this is because undergraduates do not have sufficient knowledge in the basic sciences or because the institutions cannot integrate the various disciplines. In any case, there is a high demand for an undergraduate course in nanotehcnology and to produce students who are scientifically literate in this rapidly changing technology. Already nanotechnology has been predicted to contribute $1 trillion per year to the global economy and require 2 million workers by 2015 [1].

Nanotechnology requires an integration of many science and engineering disciplines. There have been previous investigators who have proposed an integration of the basic sciences in nanotechnology courses [2]. However, they did not include the engineering disciplines in their recommendations. Furthermore, they were not able to implement their plan [3]. Within the last few years, some undergraduate nanotechnology courses have been springing up throughout the U.S. that have been taught by a single faculty member. To our knowledge, these courses have been upper-division (junior, senior and graduate) courses for more advanced students. For example, a junior-level course has been developed at Northwestern University that is taught out of the Materials Science Department which is entitled, Nanomaterials. [4] The course covered the recent breakthroughs of nanotechnology, electronic applications, molecular self-assemby, and nano/micro-electromechanical systems (N/MEMS).

In 2003, Loyola Marymount University (LMU) obtained a National Science Foundation grant to teach a new sophomore-level course that integrated biology, chemistry, physics, materials science, electrical/mechanical engineering and ethics. The title of our course was "Introduction to Nanotechnology." Its purpose was to utilize the basic and applied sciences for providing a fundamental understanding on how nanotechnology will affect the human body. This interdisciplinary course satisfied the new engineering trends that have been recommended by the American Society of Mechanical Engineers (ASME) [5, 6]. Our present course covered a broad range of the basic science, engineering, and ethical concepts; it covered the topics at a low level (with few equations and no mathematical derivations); and it was integrated between seven different faculty members.

The goal of the paper is to discuss our course content, assessment methods, integration and collaboration of the disciplines. Our new course was organized according to a common goal, central theme, learning objectives and course outcomes. The course is team-taught by faculty from seven different disciplines and is offered to both science and engineering majors. The course content is divided into weekly topics over a 15 week semester. The faculty collaborated with each other in designing the course. The course was integrated by a faculty facilitator and emphasized the biological applications of nanotechnology. The class was integrated by having interdisciplinary study teams and a team project that combined both science and engineering students.

2 COURSE CONTENT

Goals, learning objectives and outcomes. The goal of our course was to provide a descriptive view of how nanotechnology affected the human body. Our three learning objectives and course outcomes are shown in Figure 1. Because most of our students were sophomore biology students with a limited physics background, our course was taught at a conceptual (descriptive) level. We were interested in our students having the ability to understand the applications, comprehend everyday literature and know the vocabulary of nanotechnology.

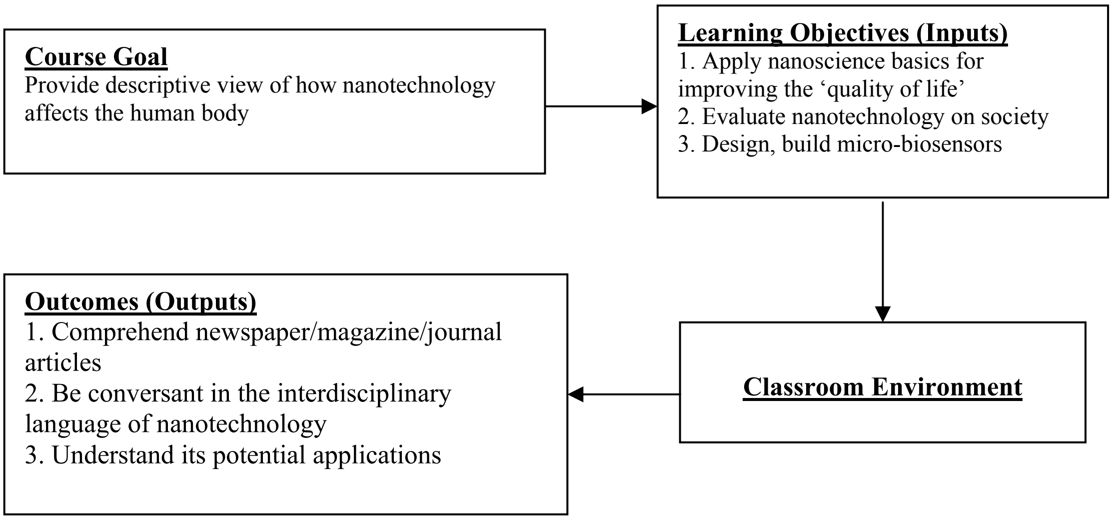

Figure 1 - Diagram of Goal, Learning Objectives and Outcomes from Our Course.

Course modules. In planning our new course, its preliminary content has been described in the 2003 ICEE conference proceedings in Valencia, Spain [7]. Since that time, we have made modifications to its content, as mentioned below and in **Figure 2**.

Our course started with an overview (summary) of the seven disciplines and their applications to nanotechnology. This was a 'systems' approach, where the individual disciplines were integrated at the top. A similar systems approach has been recommended for studying biology at institutions of higher educational in the U.S. This enabled the students to obtain a global perspective – a 'view from the top.' The students were exposed to the scaling of sizes (from large to small) – e.g., height of humans, living tissue, cells, bacteria, proteins, DNA and water molecules. The course was oriented around three applications: DNA microarrays, microfluidic (lab-on-a-chip) devices, and nano-biomedical structures.

Then moving 'top-down' in our course (not to be confused with 'top-down'/'bottom-up' processing of micro/nanostructures [8]), the individual modules were divided into the science subsystems - biology, chemistry, physics and materials science. These subsystems provided the basic understanding of evolution, mutation, genetics, molecular/cellular biology, proteins, adhesion/quantum mechanics, microscopy, current nanostructures and their affect on the human physiology. Here, two types of nanostructures were covered: (1) natural molecules manufactured by the human body (e.g., DNA, RNA, proteins), and (2) synthetic nanostructures (e.g., quantum dots, buckyballs, nanotubes, nanoshells). Because the synthetic nanostructures are at the molecular level, they were used as examples for interacting with the body's natural molecules and cells to detect and prevent diseases.

Materials science transitioned the science subsystems into the applied systems – electrical/mechanical engineering, biological applications and ethics (now moving 'bottom-up' from subsystems to system level). Materials science was the integrator of the disciplines throughout our course. This was logical because materials science, like nanotechnology, was an interdisciplinary field that incorporated such disciplines as chemistry, physics, electrical and mechanical engineering. The link between biology, physics and materials science was computer technology. Computers have enabled huge amounts of DNA/genetic data to be analyzed very quickly.

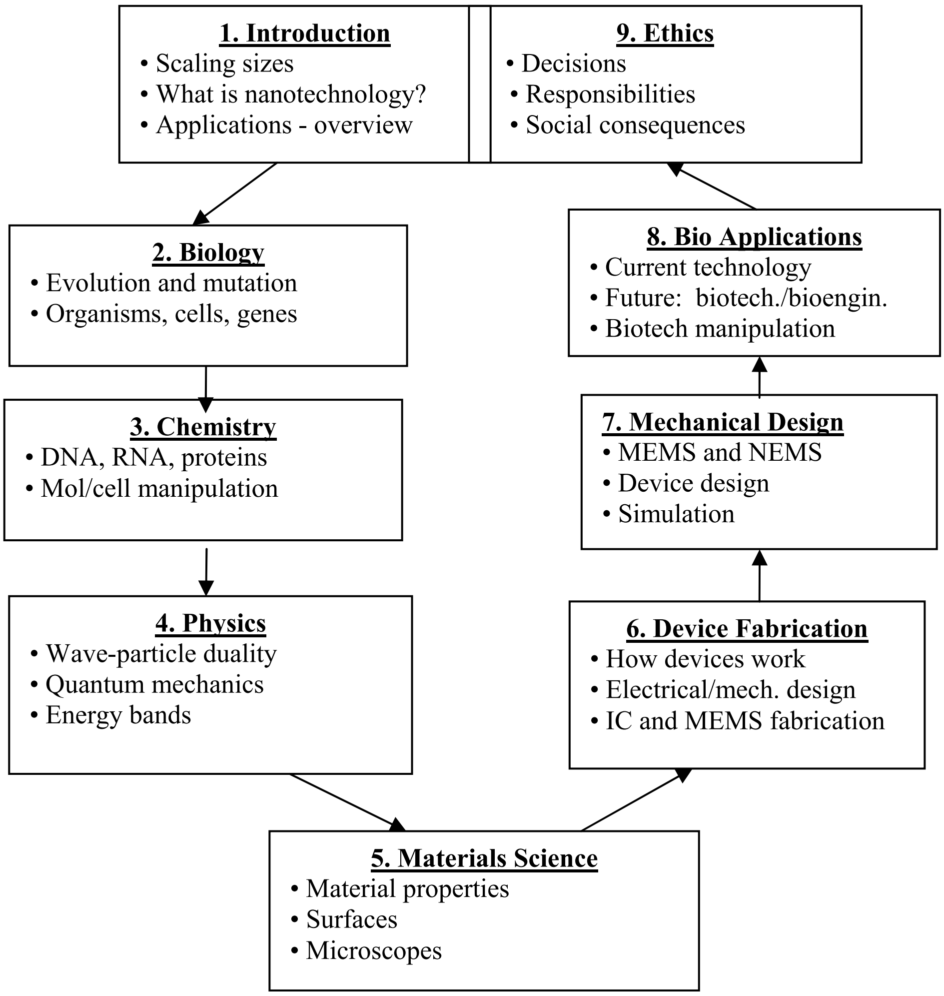

Figure 2 - Course Organization and Flow of Topics

Logic gates and binary systems in computers were explained, which led into transistors (as switches) and such synthetic materials (conductors, semiconductors and insulators). Then materials science passed the ball on to electrical and mechanical engineering.

The electrical and mechanical engineering disciplines used the basic sciences to explain how to design and fabricate synthetic micro/nanostructures for particular applications. This was our 'bottom-up' approach, where the subsystems were again integrated into the whole system that applied to applications. Electrical engineering discussed the design and fabrication of integrated circuits (IC's) and dip-pen nanolithography. Mechanical engineering discussed the design and fabrication of micro/nano-electromechanical systems (M/NEMS).

Three types of micro/nano-devices were discussed as our applications: (1) micro/nano-arrays (gene chips or biochips) for DNA analysis, (2) micro/nano-fluidics (lab-on-a-chip) for chemical/medical diagnostics, and (3) nanostructures that interact with the body's DNA, proteins and cells for disease detection and cure. Then the future applications in year 2020 were predicted and their ethical implications are discussed. In addition, the students had a class project to design, fabricate and test a microfluidic biosensor to detect the presence of DNA or a protein that is dispersed in a liquid.

3 ASSESSMENT METHODS

Several tools were used to evaluate our new course, using both summative and formative assessment methods for the benefit of the National Science Foundation [9]. Formative assessment provided internal feedback to help us revise and improve the course, which would be valuable for ABET accreditation [10]. Summative assessment showed our 'value-added' from the course. Three assessment tools were used:

- Pre-test/post-test (summative assessment)
- Fast feedback questionnaire (formative assessment)

- Post-mortem course evaluation (formative assessment)

Pre-test/post-test. This test consisted of 7-8 multiple choice questions on the most important topics of our course, covering all the disciplines. The test is administered both at the start and end of the course. The difference between the scores will demonstrate the knowledge acquired by our students (our 'value-added') after the course has been completed.

Fast-feedback questionnaire. This tool was used administered once a week to determine the students' progress in learning the course material [10]. It provided a quick, anonymous snap-shot on how the class is doing. The questionnaires gave instant feedback to the faculty and enabled them to make modifications to the course before the semester ended. The typical questions in the fast-feedback questionnaire were: "What are the most important things you've learned this week?" "What concepts are you having the most trouble learning?" "What single change by the instructors will most improve your learning?"

Post-mortem course evaluation. At the end of the semester, our course was assessed by how well we accomplished our outcomes (see **Figure 1**). Since it is administered at the end of the course, it is too late to improve the current course and hence we called it 'post-mortem.'

In this assessment tool, we used a series of 7 questions to assess our outcomes. For example: (1) Integrating the science and engineering disciplines enhanced your understanding of nanotechnology. (2) Integrating the disciplines improved your understanding of the applications. (3) The class project provided a hands-on understanding of nanotechnology. (4) The exercises and demonstrations in the classroom improved your learning. (5) Team-teaching the course helped you to become conversant and understand the literature. (6) Integrating the disciplines enhanced your knowledge of the multi-disciplinary, 'multi-lingual' nature of nanotechnology. (7) You would recommend this course to one of your friends.

Each question was scored on a five-point Likert scale, where 4 = strongly agree, 3 = agree, 2 = neutral, 1 = disagree, 0 = strongly disagree). The scores are calculated for each question and averaged for the class. An average score of 2.5 for each question was taken as our standard requirement for meeting the outcomes. If the average was < 2.5, then we took corrective action to improve our course.

This paper was written in the middle of the Spring semester 2004, when our course was first taught. Hence, the results of our assessment cannot be covered in this paper. The results will be covered during the presentation of this paper.

4 INTEGRATION OF DISCIPLINES

In a recent mini-plenary lecture to the American Society for Engineering Education, the deputy director of the National Science Foundation made the following statement: "Nature doesn't have disciplinary boundaries" [12]. This is sometimes easier said than done, because nanotechnology is a very interdisciplinary field. For example, **Figure 3** shows the disciplinary boundaries between engineering, biology, chemistry and physics in our course. Nanotechnology is at the center of the diagram, and it is flanked by such sub-disciplines as bioengineering, micro-systems design/fabrication, solid state physics, molecular physics, nano-systems fabrication, biochemistry and biotechnology. These disciplines and sub-disciplines are created at our highest institutions of learning. The discovery of new nanotechnology products and processes in the future will occur at the boundaries of these disciplines. Hence, the purpose of our course was to breakdown the disciplinary boundaries by integrating the disciplines.

The success of our course hinged on our ability to integrate the topics from one discipline to another, so that we could hopefully breakdown the artificial boundaries. In order to accomplish this, a course facilitator was selected according to his experience in integration and in motivating the faculty. The facilitator was somewhat knowledgeable in all of the disciplines because he had to collaborate with the faculty in designing the course. Due to the interdisciplinary nature of materials science, the faculty member from this discipline was selected as the course facilitator.

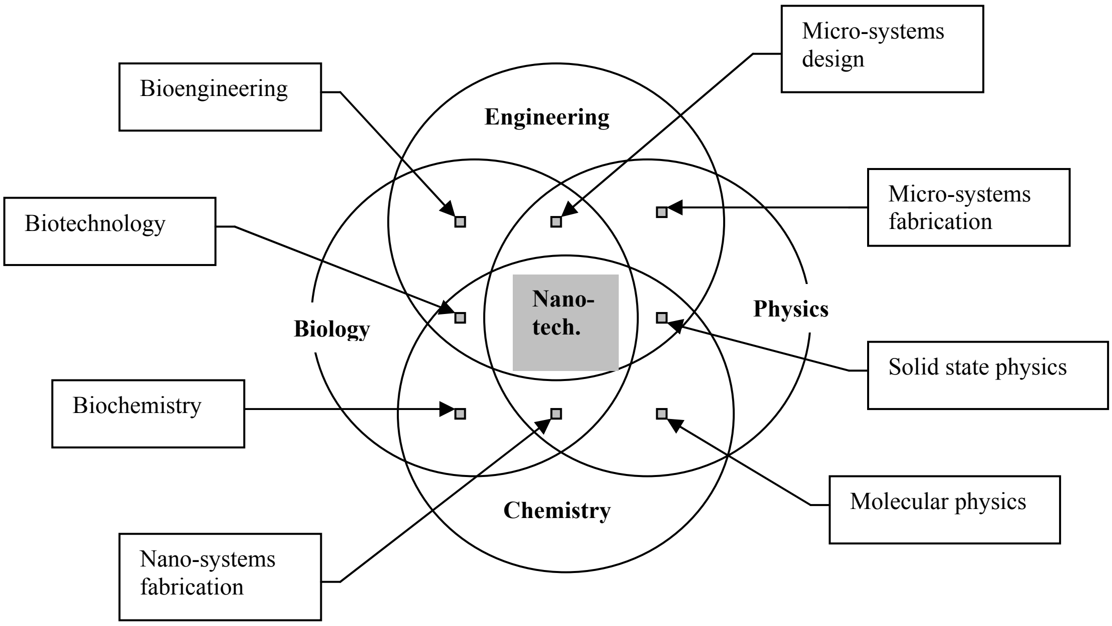

Figure 3. Venn diagram showing the interdisciplinary nature of nanotechnology (called 'nanotech.').

In planning the course, our approach on integrating the disciplines was to develop the following:

- Common theme and central philosophy
- Key applications
- Overlapping the disciplines
- Interdisciplinary student teams

Common theme and central philosophy. A common theme throughout the course established a thread that could be woven throughout the modules of the course. This was vital for integrating the seven disciplines in **Figure 2**. The selected theme was: "the effect of nanotechnology on the human beings now and in the year 2020."

A central philosophy described the general attitude that was used in the classroom. Our central philosophy was relating the macroscopic world (as seen by the naked eye) to the microscopic world (as seen under an microscope) to the nano-scopic world (as seen under an electron or scanning probe microscope). For example, relating macroscopic blood vessels to microscopic cells to the nano-scopic DNA helix spanned about nine orders of magnitude.

Key applications. Early in the planning stage, it became obvious that all of the disciplines needed to focus on the same applications. If any topics could not relate to these applications, they were removed from the course. There were three applications that were selected – DNA microarrays, microfluidic devices and nano-biomedical structures. Each discipline in **Figure 2** supported at least one of the applications. For example, with microfluidic devices, biology supported the diagnostic analysis; chemistry supported the chemical reactions in the fluids; physics supported laser induced fluorescence detection; materials science supported the properties of silicon; mechanical engineering supported the design of the micro-channels; electrical engineering supported the fabrication of the micro-channels; and ethics supported the privacy and security issues. In addition, the faculty collaborated with industrial institutions (Nanostream and NanoInk) to bring seminar speakers to our class for discussing these applications.

Overlapping disciplines. Where ever possible the disciplines were encouraged to present their lectures together, so their topics could be discussed together simultaneously. For example, overlapping biology and chemistry was obvious in discussing cells, DNA molecules and proteins. Other examples included overlapping biology and physics in discussing the application of quantum dots in diagnostic analysis; chemistry and materials science in discussing surfaces and interfaces; physics, materials science and electrical engineering in discussing p/n-type doping of silicon; electrical and mechanical engineering conducting simulated flow of fluids in micro-channels. Our intent was to reduce the gaps (or seams) when transitioning from one discipline to another. In searching for seamless integration, before each class lecture, the objectives and significance of each module was explained by the course facilitator.

Forming multi-disciplinary teams. The students were grouped into multi-disciplinary teams. There were the 29 students in the course from various disciplines: biology, natural science, physics, electrical and mechanical engineering. About 2/3 of the students were biology students and ~80% of those were women. Nine teams of 3-4 students each were selected by the faculty based on diversity according to the student's major, grade-point average (GPA), year in college, gender and ethnicity. Student diversity has been shown to be an important factor for improving performance of teams [13].

Each team comprised 3-4 students from different majors that combined the life sciences with the physical sciences and engineering. We wanted the students to learn in a team environment by collaborating with each other to reinforce the course fundamentals – both in study groups and in a class project. Collaboration in teams has been shown to enhance student learning [14]. Their class project was worth 40% of their grade and consisted of designing a biosensor, performing DNA sequencing, and doing an ethics case study. We hoped the students would develop better critical thinking skills by working in teams.

5 COLLABORATION

In order for the integration of disciplines to be successful, the faculty members needed to collaborate with each other. Prior to the formation of the course, the faculty from each discipline were selected due to their interest in teaching nanotechnology and their ability to work with others. Throughout the course planning stage, weekly meetings were held for the faculty to voice their ideas. All ideas were accepted so long as they were relevant to any of the applications. **Figure 4** shows a schematic of how the applications were the central focus of the course. Each discipline had to be relevant to the applications, and the faculty had to collaborate with each other in order to integrate the course topics.

In addition, any new ideas had to conform to the course learning objectives and course outcomes that the faculty had previously agreed upon. In this way the faculty were able to 'buy into' the collaborative process. After the weekly meetings were completed, a brief summary of the meeting was documented and e-mailed to everyone, so that everyone was kept informed of any changes.

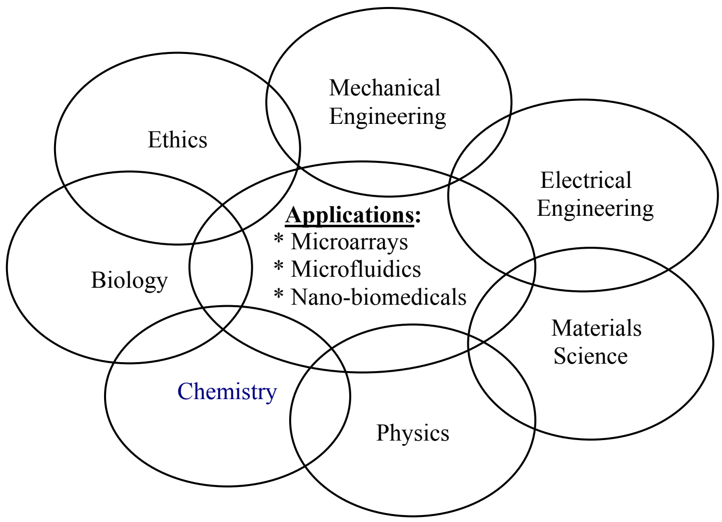

Figure 4 - Combining Disciplines Around Applications as a Central Focus.

Several important work habits emerged that related to effective faculty collaboration. These are listed below. From our experience, the faculty should be willing to:

- Sacrifice the good of their discipline for the good of the course.
- Trade/switch topics to promote better integration.
- Learn new concepts in a rapidly changing field.
- Form new inter-departmental bonds.
- Adapt to change as the course is being taught.

- Get out of their comfort zone (discipline) and make mistakes.
- Do cutting-edge teaching in order to reshape higher education.

These work habits will be discussed in more detail after the course has been completed.

6 CONCLUSIONS

A new sophomore-level course, Introduction to Nanotechnology, has been developed that integrated biology, chemistry, physics, materials science, electrical/mechanical engineering and ethics. The goal of the course was to provide a descriptive view on how nanotechnology affects the human body. The course was 15 weeks long and enrolled 29 students that majored in science and engineering. Our course emphasized three biological applications: micro/nano-arrays for DNA analysis, micro/nano-fluidics for chemical diagnostics, and nano-biomedical structures that interacted with body's DNA, proteins and cells. Materials science was selected as the integrator of the disciplines throughout the course, due to its multi-disciplinary backdrop.

In order to integrate the disciplines, several teaching strategies were used: (1) deciding the learning objectives and course outcomes up-front, in order to properly evaluate how well we met our outcomes; (2) developing a course theme and central philosophy so the faculty would focus its attention on these common threads throughout the semester; (3) creating an inter-dependency between the disciplines by having them organize their course content around specific applications; (4) overlapping the course content between various disciplines so several faculty could discuss their topics together; (5) forming interdisciplinary student teams, so the students could both work together in study groups and on their class project. Their class project was to design, fabricate and test a microfluidic biosensor to detect the presence of a liquid protein. Because this course was taught for the first time, the faculty had to be flexible in changing the direction of the course delivery.

Three tools were used to conduct either formative or summative assessment of the course. The pre-test and post-test were given at the start and end of the course, which enabled us to measure the nanotechnology "value added" (summative assessment). Fast-feedback questionnaires were short weekly surveys that detected learning problems in the classroom. They allowed us to take corrective action in the course before the semester ended (formative assessment). The 'post-mortem' course evaluation was given at the end of the course, which allowed us to assess our course outcomes (formative assessment).

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BIOGRAPHICAL INFORMATION

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