A Research Driven Multidisciplinary Curriculum in Sensor Materials

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Abstract

The multidisciplinary research at the NSF Center for Industrial Sensors and Measurement (CISM) at The Ohio State University (OSU) has led to the development of an innovative curriculum. The new multidisciplinary industry-oriented curriculum is currently being funded by the NSF-CRCD (Combined Research-Curriculum Development) program. Moreover, OSU's Honors House is funding an interdisciplinary course on "Sensor Materials," targeted for honors students in engineering and physical sciences. This multifaceted program is strengthening ties between the federal, state, university and industry partners. The greatest benefit has come from introducing industry projects into the university's engineering and physical sciences, thus providing students and faculty the opportunity to work on research relevant to industry.

I. Introduction

On most campuses of higher education with significant research activity, there is a continuing debate on the appropriate balance between research and education. Should we be doing more of one at the expense of the other? Also, in research, there is a growing trend of multifaceted partnerships involving academia, government, national laboratories and industries. Such partnerships in education are almost nonexistent. With changing societal needs and demands, the way we educate and train the future generation of engineers will evolve. We will need to integrate the latest research developments into students' curriculum more readily and train students in a cooperative environment with involvement from industries. This will help students appreciate the impact of their education on society and will also help develop skills useful for their future careers. This paper describes a novel curriculum development that grew out of what started as a major multidisciplinary research effort involving several partners. This example shows the synergistic benefit of such an approach and reinforces a prevalent belief that innovation in research can help enrich education.

Under the umbrella of the NSF Center for Industrial Sensors and Measurement (CISM), a research and development program for harsh environment sensors is being actively pursued at The Ohio State University (OSU).[1-4] Research teams include students and faculty from the

Departments of Chemistry, Physics, Materials Science and Engineering, Electrical Engineering, Industrial Engineering, Chemical Engineering and Mechanical Engineering. CISM's organizational structure provides a framework for interaction among scientists, engineers, students and business leaders. Students from various disciplines closely interact with each other, as well as with scientists and engineers from industries and national laboratories. Exploiting the collaborative environment of CISM combined with research advances in sensors, we have started to develop an innovative classroom and industry-oriented curriculum. CISM research has three primary research thrust areas: (1) polymer sensors and devices for biomedical applications, (2) ceramic sensors and devices for industrial process control and environmental pollution monitoring and (3) smart systems involving sensor arrays (e.g., "electronic nose" for ceramic sensors and "electronic tongue" for polymeric sensors) integrated with artificial intelligence and pattern recognition. Figure 1 highlights the three thrust areas of CISM leading to the curriculum development.

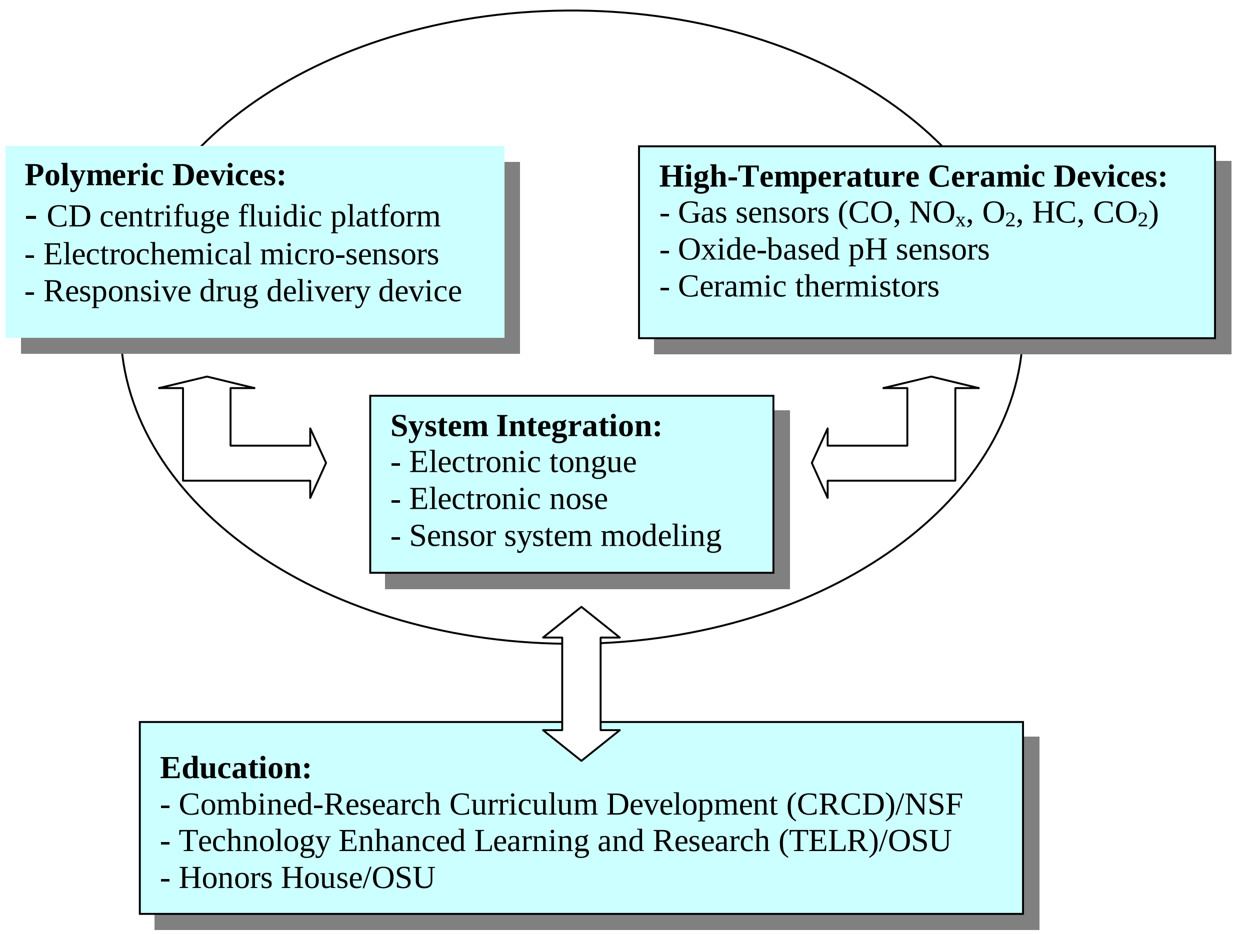

Figure 1 CISM research and education thrust areas.

The curriculum is designed around the multidisciplinary approach of CISM and focuses on an interactive approach emphasizing problem solving, team work, communication, and industrial experience. Workers in the 21st century will need skills beyond the technical, such as management, leadership and ethics. Plans include expanding the students' technical education to include business, management, administration and law. Emphasis will be on such issues as product design and liability, problems created by new technologies, protecting intellectual property, technology transfer and the relationship to the Internet.

A three-course sequence (9 credit hours) in sensor materials including instructional laboratories with industrial experience is being developed. These courses are being designed from a multidisciplinary approach and are team-taught by faculty members from a wide range of disciplines. These courses are targeted for senior undergraduate and starting graduate students. Students taking this sequence along with 11 credit hours of relevant courses in participating departments including Business and Law will have the option to receive a minor or certificate degree program in "Sensors and Measurements". Figure 2 summarizes the essential components of the curriculum being developed. Moreover, students will be able to take these courses and count them toward technical electives as required by their degree program.

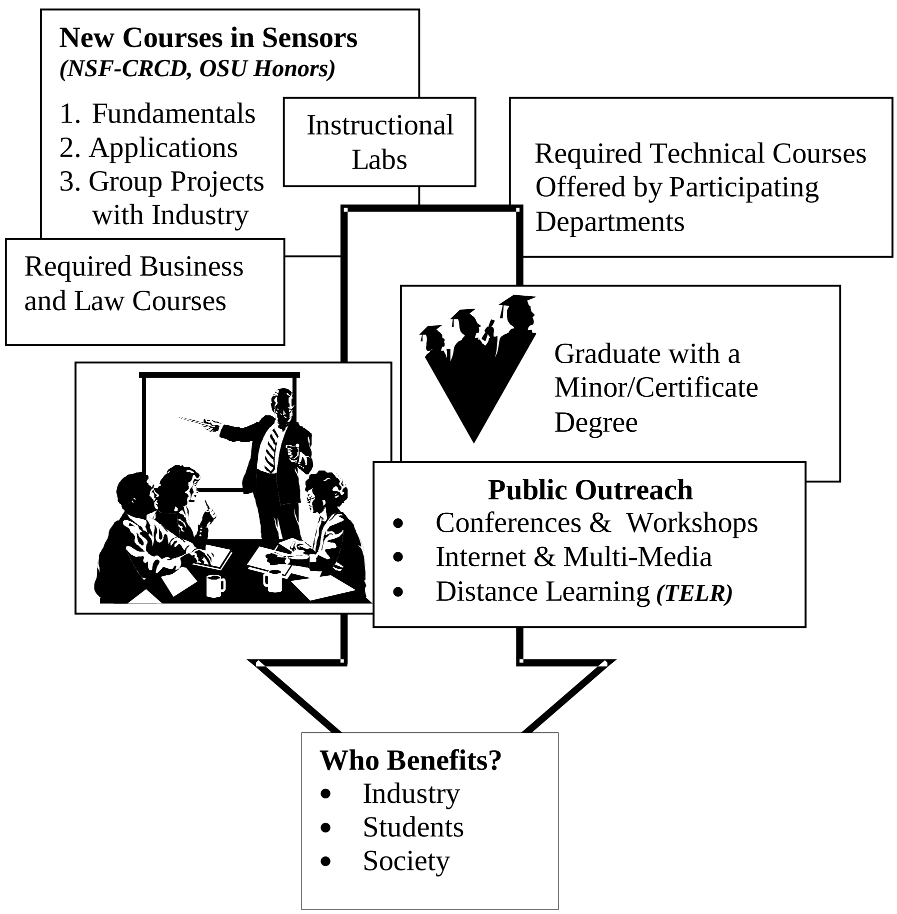

Figure 2 Summary of CISM-CRCD curriculum development program.

Further enhancing the NSF-CRCD program, CISM was awarded funding by OSU's Honors House to develop a 5 credit hour interdisciplinary undergraduate honors course in "Sensor Materials." This course is intended to be a condensed version of the three-course sequence being developed under the CRCD program. This honors course is being offered for the first time during the current quarter (Winter, 2000). This course has three parts: (i) lectures covering basic scientific and technological principles, (ii) laboratory experiments demonstrating fundamental aspects of sensor fabrication, characterization and sensing mechanisms, and (iii) group projects with industrial relevance. The results of the honors course will be reported in a future publication. Recently, we received another OSU grant for enhancing web-based learning at OSU from the Technology Enhanced Learning and Research (TELR) program. This will further enhance our already strong web-based sensor courses (http://www.biomems.net and http://m04.cism.ohio-state.edu/nsf.crcd.)

II. Course Development

A. Sensor Materials: Fundamentals

The first course, covering basic scientific principles of sensor materials, has been taught for the first time during the Spring Quarter of 1999 as a 3 credit hour course. In its first offering the course was taken by 10 students for credit and 5 students audited the course. Undergraduate enrollment was very limited, because it is difficult to fit in a new course on a short notice into their pre-determined curriculum. Future offerings will need to be advertised well in advance to a wider pool of students.

The actual lecture notes can be downloaded from the CRCD web-site: http://m04.cism.ohio-state.edu/nsf.crcd. Students were given a grade based on: (1) attendance in lecture sessions; (2) submission of a written term-paper (Table I); (3) presentation of the term-paper followed by questions and answers from the audience and (4) completion of a computer simulation model of an oxide-based gas sensor.

A1. List of In-Class Lectures

Introduction
Technological needs and justifications
Ceramic and polymer sensors for high-temperature and bio-medical applications

Synthesis and Fabrication
Powder synthesis
Nano-phase materials
Thick and thin films
Wet and dry etching
Dip-stick method
Bio-MEMS

Surfaces, Interfaces and Catalysis
Molecular recognition
Chemistry and defects
Adsorption and desorption
High-temperature catalysts

Characterization of Sensors
Structure and microstructure
Surface and interface
Optical spectroscopy
Electrical and sensing properties

Theory and Modeling
Sensing mechanisms
Microstructure-property relationship
Sensor arrays and pattern recognition

A2. Term Paper

Each student wrote a comprehensive review paper on a selected topic. Examples of term paper topics are shown in Table I. Papers were limited to 20 pages with major emphasis on the status of current literature leading to identification of outstanding challenges and future trends in the chosen topic. Each paper was graded by two faculty members and significant weight was given to the depth and level of critical discussion. Each student made a presentation followed by questions from the audience. The quality of the presentation was judged by multiple faculty members and the peer group of students in the class. The term papers have been archived in the CISM library and can be accessed as reference materials.

Table I: Examples of term papers written for course in "Sensor Materials"

Paper Number	*Term Paper Title*
1.	Overview of MEMS and its applications to sensors
2.	Sensor fabrication and manufacturing technologies
3.	Artificial muscle
4.	Chemical sensors for biomedical applications
5.	Thick versus thin film gas sensors
6.	Challenges in Non-silicon MEMS
7.	Physical methods for surface characterization of ceramics
8.	Sensor arrays, neural network and pattern recognition
9.	Zeolites as sensor materials
10.	Lithography process in miniaturized sensor fabrication

A3. Computer Modeling

Recognizing the growing importance of computational science & engineering (CSE) in modern technological advancements, modeling and simulation forms a key module of the curriculum. The research achievement on computer modeling and simulation at CISM is uniquely suited for adoption in undergraduate and graduate instruction because it involves the design and optimization of sensor materials and extensive visualization. In particular, in the computer-based modeling lab entitled *Gas Sensor Design by Computer* the students were able to control the sensing behavior by material and processing choices and see how a sensor responded to ambient gases. The students were divided into groups and worked as a team to explore the features of electrical conduction through a granular composite gas sensor. Each group was given a goal to design a ceramic gas sensor for CO detection with optimal response properties. A simplified version of our computer research code was installed in a computer simulation lab in the Physics Department, where 10 PCs are connected in a teaching network. The physical and mathematical models behind the programs were covered in the lectures. The students were given instructions on how to run the program, the input parameters and the output data in the lab. Then they were on their own to design two types of sensors: a linear gas sensor and an on-off gas sensor. They were asked to optimize the performance of each sensor by adjusting the values of the input parameters including the desired microstructure, the desired surface chemical properties in terms of the energy levels, and the desired electrical properties of the grain and grain boundary regions. The modeling code was provided on-line so students could work at home or on other computers on-campus.

B. Sensor Application and Manufacturing

The second course will cover sensor application and fabrication/manufacturing related issues including micro-machining and miniaturization. Lectures in the application area will range from chemical sensors to bio-, rf- and optical-MEMS. The manufacturing area will include topics such as thick and thin films, micro- and nano-machinig, replication techniques, and soft lithography. This course will also have a laboratory demonstration component. For the demonstration part, students will have access to CISM laboratory facilities including a newly assembled hybrid electronics laboratory that houses the "electronic nose" (donated by Alpha MOS Co.) with software for artificial intelligence and pattern recognition. Other CISM facilities include powder processing and heat treating, gas sensor measurement setup, thick film deposition (screen-printing and spin coating), thin film (under construction) and a wide range of electrical measurements & testing capabilities. This course will be offered for the first time in the Spring quarter of 2000 and will include guest lecturers from a wide range of industries.

C. Group Projects with Industry

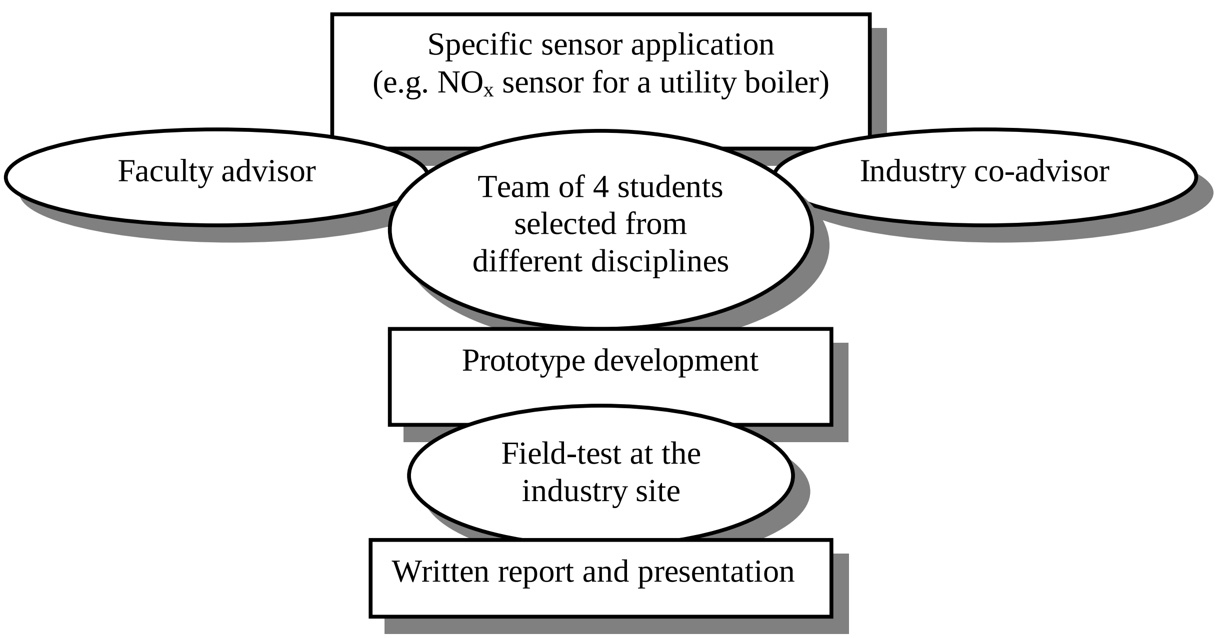

Figure 3 Summary of group projects with industry.

The third course will be group projects with participating industries. Group projects will target specific industries, identify a sensor need, develop a prototype and perform field-tests. Each project is a team effort involving multiple students working in close collaboration with a faculty adviser and an industry co-adviser. Teams will be selected to ensure that students from different disciplines interact and learn from each other. Such interaction would be extremely valuable to make up for any deficiencies in background required to take this course. An essential component of these group projects will be *Industry Internships* where students spend an extended period at selected industrial sites performing field tests. Each team will be required to submit a written report and make an oral presentation. Figure 3 summarizes the essential components of this course. These types of projects will help students understand the impact of their education on the society and will also help develop skills useful for their future careers. The first offering of this course is being planned for the Fall quarter of 2000.

These group projects will integrate the effort already being carried out in CISM research as part of probe design and field-tests. CISM students have designed probes for both CO and NO_x sensors and tested them in the Engine Emission and Diagnostics Laboratory at the Center for Automotive Research (CAR) at OSU.[5] This facility includes an FTIR analyzer (Nicolet, Rega 7000), which is capable of analyzing and quantifying 20 possible components of the gas mixture on-line while the engine is running. Figure 4 shows an example of a thick-film CO sensor probe that has been tested inside the exhaust manifold of a Ford V8 engine at CAR. Similar probes can be designed for tests in other application environments such as smoke-stacks, heat treating furnaces, utility boilers and glass melting furnaces.

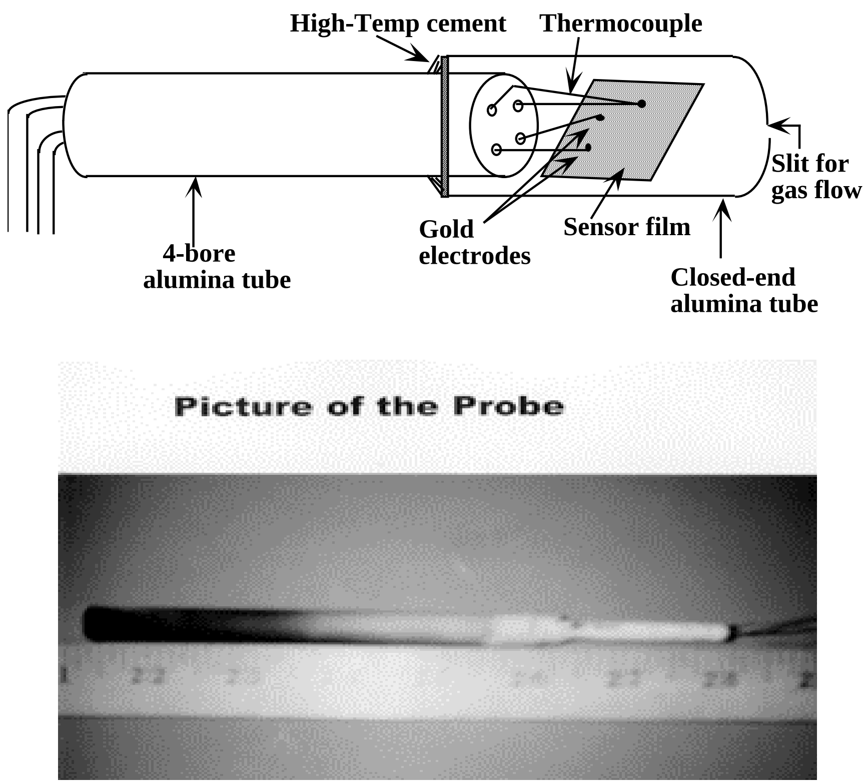

Figure 4 Schematic and the photograph of a CO sensor probe developed at CISM.

III. Assessment Plans

For the course offered in the Spring of 1999, no formal student evaluation was collected. For the honors course currently being offered, students will be asked to complete a questionnaire, designed by the OSU Honors House. Also, a web-based course evaluation is currently being developed for the future offerings to provide feedback and evaluation of the approaches and materials used in the course. Both the CISM University Policy Committee and the Industrial Advisory Board are supportive of the proposed curriculum and will evaluate the program as it progresses. Future evaluation plans include the formation of an external committee consisting of representatives from academia, national laboratories and industries to review the curriculum. Also, statistical surveys will track students in the program aimed at determining the success of the program in preparing them for their careers.

IV. Dissemination Plans

The results of this curriculum development effort is being disseminated through two mechanisms. The first is the presentation and publication of papers describing the curriculum together with descriptions of sample capstone design projects and the participation of industrial sponsors in these projects. Papers are being presented at the Frontiers in Education Conference, and at other professional society meetings and symposia. For example, CISM faculty have presented the curriculum plans at: (1) the International Conference on Engineering Education (ICEE-98 and ICEE-99)[8,9] and (2) Education Symposia of professional societies such as The American Ceramic Society, and The Minerals, Metals and Materials Society Annual Meeting.

The second means will be the establishment of an Internet site for computer-aided instruction and distance learning. This will further enhance our current effort of posting lecture materials on the internet: http://www.biomems.net and http://m04.cism.ohio-state.edu/nsf.crcd). Video and multimedia instruction will be developed and used as teaching tools using the TELR grant. Moreover, the existing OSU distance learning system that connects classrooms to off-site participants will be used. This interactive television originating live from specially equipped classrooms will be videotaped and disseminated among participating universities. Course materials will be made available through Internet, videotapes and animation CDs.

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