Celebrating the Life and Work of J. Tinsley Oden: A Pioneer and a Mentor in Computational Mechanics

J. Tinsley Oden's Vision for an Interdisciplinary Graduate Program in Computational Engineering and Science

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Abstract—Professor J. Tinsley Oden had a tremendous impact on graduate education at the University of Texas at Austin and beyond. An attempt is made to explain his overall vision for a true interdisciplinary education in computational engineering and science. The graduate program he established in 1993 is discussed. The early program was relatively small and called the Computational and Applied Mathematics graduate program. Around 2003, the program entered an expansion phase, culminating in a change to the name Computational Science, Engineering, and Mathematics. Issues of administration, coursework, and expectations for success are examined.

The research prowess of J. Tinsley Oden is well known to the computational mechanics community. His work is innovative, visionary, and pioneering in manifold areas of the field. Less known, perhaps, is his correspondingly influential impact on graduate education. He had a vision for interdisciplinary graduate education and a resolute plan for bringing it into reality. His ideas have formed the basis for the graduate program at his home institution, and his overall vision has been emulated at many institutions worldwide.

Dr. Oden believed that a successful interdisciplinary graduate program in the area of—as we call it today—computational science and engineering (CSE) would be a rigorous program of work that was both broad and deep. It would lead to research that was motivated by and addressed important scientific, technological, and engineering problems facing society, including some of the most difficult and pressing *grand challenge* problems, through the use of mathematical modeling and computational simulation. Dr. Oden recognized that to make progress on many of these challenging problems, teams of researchers with expertise in multiple disciplines were required. Critical to their success would be individual team members trained in an interdisciplinary environment. Such individuals would be able to effectively communicate with each team member, and to contribute in novel ways because they understand, at least on some level, all facets of the problem.

A student aptly trained would produce a dissertation that was unlike what one would produce in a disciplinary environment. Indeed, if the dissertation could be accepted in an existing disciplinary program, he saw no justification for a new paradigm.

Organizing Principles

Dr. Oden's conception was to view the field of CSE, or *Computational Engineering and Sciences* as he preferred to call it, as being organized into three concentration areas, each of which needed to be incorporated into a graduate student's educational plan and research. He simply designated these areas as Concentration Area A, B, and C.

- Area A. Mathematics was intended to be a core discipline in the program, providing the student with the mathematical foundations of the computational sciences. Area A was termed *applicable mathematics.* The word "applicable" was chosen rather than "applied." J. Tinsley Oden was a master of the English language, and those close to him knew his love of and expertise in poetry. His choice of the word "applicable" was deliberate. It means "relevant, appropriate, and capable of being applied." The mathematics studied by students should be relevant and appropriate to the targeted applications of their research (Area C). It could include topics traditionally studied by applied mathematicians, but it could also include more fundamental and theoretical material. By the time they graduate, students would be expected to understand at a deep level the mathematics relevant to all aspects of their research, and to have developed new mathematical ideas if they had been required.

- Area B. The unifying theme of the program would be computational modeling and simulation. Area B was identified as *numerical analysis and scientific computation.* Although including programming skills and important ideas from computer science, the area was viewed as more general, including all aspects of computational science and the algorithms used or created by the student in their computational modeling effort. A student should develop a deep understanding of all aspects of the computational algorithms, including accuracy and efficiency, the mathematical underpinnings, practical concerns, and issues of implementation.
- Area C. The broadest area of the program was identified as *mathematical modeling and applications,* referring to some natural, engineered, social, or other system. Area C could relate to virtually any area of science, engineering, medicine, or the social sciences. Each student might study a different area, but the specific application was intended to drive the research as a whole, with support from Areas A and B.

Dr. Oden had an insatiable appetite to learn, and he expected the same for CSE students. To put it simply, he expected students to take a lot of courses! He believed that success in CSE nearly required earning the equivalent of three master's degrees, one in each Concentration Area. The dream was that a student's research and dissertation would demonstrate an interdisciplinary theme and draw on knowledge from the three Concentration Areas to address important problems in engineering and science for the benefit of society as a whole.

Dr. Oden was concerned that natural biases inherent in the traditional academic disciplines and departments could derail truly interdisciplinary research and education. He felt that it could be accomplished only with hard work and cooperation between the individuals involved, both faculty and students. He envisioned a new and special class of academician, equipped with tools from modern mathematics and computer science, and understanding how these disciplines impact important areas of mathematical modeling and simulation. This educational and intellectual experience would need to include students competing and interacting with, and learning from, other students with different backgrounds.

Implementation: Program Formation

An interdisciplinary graduate program requires the appropriate infrastructure.

In 1973 Dr. Oden founded the Texas Institute for Computational Mechanics (TICOM). It was a relatively small research group, but it became the basis for something much larger.

With support from the O'Donnell Foundation based in Dallas, Texas, the interdisciplinary *Texas Institute for Computational and Applied Mathematics* (TICAM) was established at the University of Texas at Austin under the direction of Dr. Oden in the Spring Semester of 1993. The purpose of the institute was to provide infrastructure and intellectual leadership for strong interdisciplinary academic and research programs in computational science and engineering, computational and applied mathematics, and, later, information technology. To achieve a true interdisciplinary environment, the institute was founded directly under the Office of the Vice President for Research, and it reported to the Vice President and, at the start, to the Dean of the College of Engineering and the Dean of the College of Natural Sciences.

The associated faculty were initially drawn from a relatively small number of departments in the Colleges of Engineering and of Natural Sciences. Over the years the scope of the institute expanded to include faculty from essentially all engineering and science departments, as well as faculty from medicine and some of the social sciences. TICAM was renamed the *Institute for Computational Engineering and Sciences* (ICES) in the year 2003. To honor its founder, Professor J. Tinsley Oden, the name was modified in 2019 to the *Oden Institute for Computational Engineering and Sciences*.

Establishment of the program

Under Dr. Oden's leadership and astute negotiations with university authorities, his vision for an interdisciplinary graduate program was realized. The program was established within TICAM in September of 1993 with the name *Computational and Applied Mathematics* (CAM). The name CAM was chosen for the graduate program to reflect the preferred terminology of the time for this area of interdisciplinary study. As the term "Computational Science and Engineering" became increasingly popular, the name of the graduate program was changed in 2010 to *Computational*

Science, Engineering, and Mathematics (CSEM). The addition of the word “mathematics” emphasized the central role of mathematics in the program.

Dr. Oden realized that the program, much like the Institute itself, could maintain an interdisciplinary nature—in content, scope, and structure—only if it were free from the specific concerns of the university departments. CAM was established directly under the Graduate School, as an *intercollegial program*, bypassing any departmental affiliation. Although the program was primarily a doctoral program, both Ph.D. and M.S. degrees were offered.

The first students were accepted into CAM in January 1994, and the program grew to 21 Ph.D. students by the start of the 1995 academic year. At that time, 48 faculty members from engineering and natural sciences were affiliated with CAM. Given their research interests, students were expected to hold degrees in engineering, computer sciences, physics, or mathematics. The number of students in the program was to be determined by the quality of the applicants, not by any perceived need to admit more students.

Program Administration

Program administration was delegated to an oversight committee of nine elected faculty drawn from TICAM with combined research expertise representing the three Concentration Areas. Dr. Oden served on the committee from its inception until about 2007. The committee met regularly to flesh out the overall vision for the program. Through much trial and error, and the occasional heated debate, an environment of continuous improvement was engendered.

The oversight committee managed the expectations, focus, and rigor of the program, including the various coursework requirements, examinations, admissions policies, and other such concerns. In CAM, the committee also monitored carefully the work and progress of each student. Every CAM student was expected to make steady progress toward the completion of the degree.

Coursework and Examinations

A set of core courses was identified that at least most CAM students would take. These courses would expose the students to a broad range of ideas and techniques covering the entire spectrum of CSE. All CAM Ph.D. students were expected to demonstrate a graduate-level proficiency in the three Concentration Areas. Dr. Oden believed that high academic standards required a rigorous examination of the students’ progress in the program. The courses would also be the basis for the preliminary examinations taken at the end of two years of study.

Initially, no new courses were added to the curriculum; rather, courses were cross-listed with the academic departments, who controlled their staffing and content. CAM students sat in the same classes taken by students of the discipline and taught by disciplinary faculty.

- Area A. It was decided that students in the program should begin their study of higher level mathematics by studying *Basic Operational Mathematics* and *Foundations of Modern Analysis.* An existing three-semester course sequence developed in the Aerospace Engineering and Engineering Mechanics (ASE/EM) department covered these topics in semesters two (Spring) and three (Fall). These courses became the foundation for Area A, although taken in reverse order to the intent of the ASE/EM department. The lecture material of the third semester course was published as a textbook entitled *Applied Functional Analysis* [1]. Despite the name, the time constraint of a single semester led to an emphasis on the foundational material of the textbook.

  In the second year, students were expected to take a fundamental course in functional analysis and related topics in partial differential equations. Negotiations between the Mathematics department and the CAM program resulted in a new syllabus for an existing two semester course, *Methods of Applied Mathematics.* This course was and continued to be the foundational course taken by students of applied mathematics. The course name was left alone, but the level of mathematical rigor was considerably advanced. The content of this course was eventually published as a textbook entitled *Functional Analysis for the Applied Mathematician* [2].
- Area B. Students were required to take existing courses on *Numerical linear algebra*, *Numerical Analysis*, and *Parallel Computation* offered in the Computer Science department, as well as *Numerical Treatment of Differential Equations* or *Probability* offered in Mathematics.
- Area C. Finding appropriate courses in Area C proved challenging, since the topic is broad and each student may be focused on a different application area. A one semester course was designed to cover the basic principles of mathematical modeling. The course was team taught in segments. The overall instructor was

usually a member of the ASE/EM department, and the course was taught as an advanced graduate course. Guest instructors from within TICAM would cover a specific topic related to their expertise for a week or two.

Beyond the modeling course, students would take three additional courses appropriate to their application area. A limited set of Area C focus areas was formally identified that reflected the research interests of the faculty. The student, with guidance from his or her Ph.D. advisor, was required to develop an individualized program of study in one of these Area C focus areas.

In a small program, oral examinations can be quite attractive to faculty. They tend to be quite intimidating to students. Oral examinations were used in Area B, but they proved difficult to administer. Eventually all examinations were written. The Area C examination was tailored to the particular focus area of each student.

After passing the preliminary examinations, the student was expected to prepare a dissertation proposal featuring their interdisciplinary project containing elements of the three Concentration Areas. This proposal was to be defended, and an oral examination passed.

After completing the research, as in virtually any Ph.D. program, the final step was to write a dissertation, present it publicly, and defend it in front of select faculty members.

Some keys to success

By all indications, graduates of the program were highly valued. Students completing the program found good positions within academia, industry, and government laboratories.

It cannot be overstated to say that TICAM was key to the success of CAM. It provided and maintained an interdisciplinary environment, as well as contiguous office space for its researchers to foster their interaction and camaraderie. Also key was the farsightedness and dedication of the faculty, who embraced Dr. Oden's vision. The student's themselves were a special sort, willing to take the risks required to go beyond the comfortable confines of disciplinary research to engage in something much grander, which at the time was relatively speculative and undeveloped.

Private support from the O'Donnell Foundation was critical in the success on CAM. An endowment was established to award fellowships to outstanding students, attracting some of the best and brightest to the program. These fellowships also allowed students to focus on academic studies early in their career. The Foundation was also instrumental in providing a dedicated and technologically state-of-the-art building near the center of the university campus to house TICAM and the CAM graduate program. Opened in 2000, the *Applied Computational Engineering and Sciences* building was renamed the *Peter O'Donnell Jr. Building* in 2013.

Implementation: Program Expansion

Starting in 2003 with additional donations from the O'Donnell Foundation and also now from the philanthropy of William "Tex" Moncrief, the scope of TICAM expanded greatly. More faculty were recruited to be associated with the institute, renamed ICES, from a wider range of engineering, science, social science, and medical departments. Demands on the CAM/CSEM program increased, and it grew over the years to around a hundred graduate students with a broader set of undergraduate backgrounds. Moreover, approximately another hundred students from disciplinary graduate programs reside in the institute. A number of issues proved difficult to manage as CAM/CSEM grew in size and scope.

Enabling an expanded scope

A new set of rules for the Ph.D. program was codified in 2001. It introduced a number of changes. Originally, students were expected to take a heavy course-load of twelve courses in Areas A, B, and C over two years and then be tested on the material. This was relaxed to a one year time-frame of six courses and their respective examinations. Each student was still required to take an additional six courses, two in each Area, but within a flexible additional time of two and a half years and with no additional testing requirements.

The program introduced two degree Options for the first year, the *CAM Option* is designed for students with a strong mathematics background. These students do not need to take the ASE/EM mathematics courses. Rather, they are ready to begin their study of applicable mathematics with the applied mathematics students in the course that is cross-listed with mathematics, Methods of Applied Mathematics (which is actually Functional Analysis). The *CSE Option* is designed for students not ready for the mathematical rigor of the CAM Option course. It continues to use the two courses offered in the ASE/EM department. It is no longer required that these students take the Methods of Applied Mathematics course in subsequent years. Each Option has its own preliminary examination.

The first year Area B course topics were fixed as numerical linear algebra in the first semester, since basically all students of CSE need such a course.

The second semester allows students to diverge in the types of computational algorithms their research would require. To remain manageable, only two topics were allowed. Numerical approximation of differential equations is one possibility, and the other has morphed from probability to discrete mathematics to, today, machine learning and data science. The preliminary examination covers the two courses that the individual student actually took.

Administration of the Area C focus areas and preliminary examinations had proved to be taxing to the faculty and worrisome to the students. The solution agreed upon was to open up Area C to any area investigated by the student and his or her advisor. Moreover, the one semester modeling course was replaced by a dedicated and rigorous two semester course on the principles of modeling, covering most branches of mechanics (nonlinear, statistical, and quantum) as well as electro-magnetism and the life sciences, depending a bit on the interests and expertise of the two faculty members teaching the course each year. Dr. Oden taught the first semester for several years, and he produced a textbook on its content entitled *An introduction to mathematical modeling: a course in mechanics* [3]. The content of the preliminary examination is now clear to the students.

The common course requirements give a strong foundation for subsequent research in CSE. They also engender interactions among the students with different backgrounds, as they help each other learn the material.

Offering new courses

It should be clear that the expanded CAM/CSEM program required new courses in the curriculum. Offering CSEM graduate classes in an interdisciplinary setting has proven to be a major challenge, since all instructional resources flow through the departments at the University of Texas at Austin. Nevertheless, the Oden Institute has managed to gain control of the content of several courses, and staffed them with appropriate Institute faculty, albeit sometimes only after negotiation with the departments of the assigned faculty instructors.

The first year Area C course is now controlled and staffed by the Oden Institute. A second year course entitled *Tools and Techniques of Computational Science* was developed to introduce students to the practical use of high performance computing hardware and software engineering principles for scientific technical computing. It is not required, but many students find it helpful. Several of the first year courses are very popular among graduate (and undergraduate) students from other programs. Included are the first year Area A-CSE courses, the Area A-CAM courses, the Area B courses on numerical linear algebra and machine learning, and the course on tools and techniques. The Oden Institute now controls several of these courses.

Additional comments

The oversight committee was expanded to twelve members to better reflect the diversity of the faculty. The Oden Institute's external review board, the Board of Visitors, took an active interest in CSEM and contributed to its development.

The program continues to grow and evolve. As an example, when the program was small, almost all students were supported through a fellowship of some kind. Today, more and more students are supported by research projects in their first year. This has led to a relaxing of some of the first-year course requirements for such students. An interdisciplinary program must remain flexible within its overall structure, without compromising its academic rigor.

CONCLUSION

By now, almost 200 students have graduated with a doctorate in CAM or CSEM. It was expected that graduates trained in a true interdisciplinary environment, emphasizing the full gamut of CSE, would find a diverse array of employment opportunities. Dr. Oden would even go so far as to quip that our graduates would be able to go "anywhere thay wanted." In fact, upon graduation, about 53% of the alumni started their careers in academia, normally as post-doctoral scholars; about 36% began an industrial career; and the remaining approximately 11% began a career in a government laboratory. They have gone on to become leaders in their respective institutions all over the world. It is probably safe to say that the impact of the Oden Institute and the CAM/CSEM program on computational science and engineering has been enormous and continues to grow.

Dr. Oden had a grand vision for the potential of interdisciplinary research within CSE on resolving a wide range of problems facing society today. A significant part of that vision was in terms of the education of researchers having an interdisciplinary mindset. You can read his own words on the subject in his writings, such as the articles [4], [5].

Despite his busy schedule, Dr. Oden made it a point to greet the incoming class of CSEM students each year. In his later years, he would often discuss a subject that fascinated him and set the stage for graduate inquiry: the issues of knowledge creation, the scientific method, and implications of Bayesian theory. Professor J. Tinsley Oden's vision for interdisciplinary education in CSE lives on in the lives of his students, colleagues, and graduates of the CSEM program and countless other programs inspired by his ideas.

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