Learning as Problem Solving

Carnegie Mellon University
Proposal for a Recognition Award for the Integration of Research and Education

Interdisciplinary problem solving is the cornerstone of a Carnegie Mellon education, especially in engineering and science. The focus on problem solving enables faculty and students to work together across disciplinary boundaries. Both the small size of the university and the support by the administration facilitate interdisciplinary problem solving. A pragmatic approach permeates educational as well as research activities. In this proposal, we present three activities that illustrate Carnegie Mellon's commitment to integrating research and education.

1. Research as a learning vehicle in the classroom,
2. Independent research by students throughout their academic career, and
3. Facilitation of classroom learning.

University Vision

In 1948, Richard Teare, then professor of Electrical Engineering at Carnegie Institute of Technology (later Dean of Engineering) described how students were being taught to discover the "order in the apparent chaos of reality" by engaging them in solving professional problems. This view that education is problem solving, rather than knowledge transfer, has two important consequences. First, courses are designed to emphasize problem solving as the central activity of learning, which naturally bring research into the classroom as students search for the knowledge and skills needed to solve problems. Second, since real problems are complex and rarely fall within disciplinary boundaries, interdisciplinary learning and practice are routine in the classroom.

The fostering of interdisciplinary research has given rise to many centers of excellence at Carnegie Mellon. For example, Carnegie Mellon has one Science and Technology Center, the Center for Light Microscope Imaging In Biology, and two NSF Engineering Research Centers: the Engineering Design Research Center and the Data Storage Systems Center. These centers have strong educational programs that bring together students, staff and faculty from many different disciplines to work on a central problem.

Integrating Research and Education

1. Research as a learning vehicle in the classroom

Many courses at Carnegie Mellon engage students to work on a current research project. Research and implementation may be the mode for the entire course or for part of the course. This teaching method, long in use at Carnegie Mellon, uses project-based learning. Three examples of this method are the Software Engineering course, the Technology Policy Project, and the Rapid Design course. When describing these courses to colleagues at other schools, the faculty have been met with disbelief: both that undergraduates can deliver cutting-edge research results in a semester and that the institutional barriers to creating these innovative, interdisciplinary courses are so low.

In the undergraduate Software Engineering course, offered since 1989, students work through a software project from requirements to prototype acceptance testing with a client. Projects have

included creating a computer diagnostic maintenance system for the people mover at the Pittsburgh International Airport, an interactive emergency navigational database for the Chief of Police of the Bellevue Police Department, and an air quality and pollution modeling system for the EPA. Students learn to work in multidisciplinary teams of technical writers, graphic designers, engineers and computer scientists. For several years, starting with an NSF laboratory instrumentation grant, the course has leveraged new technology (specifically, portable computers with wireless networking) to stimulate student and client interest in cutting-edge projects. This has led to cross-fertilization with the other research projects on campus, such as the wearable computer project at the Engineering Design Research Center.

The Technology Policy Project, offered since 1970, is a core course for undergraduates in Engineering and Public Policy and in Social and Decision Sciences as well as graduate students in the Heinz School of Public Policy. Students work in interdisciplinary teams to solve a real-world problem, reporting the results to a diverse panel of experts. In a recent project, students worked on the problem of large appliance disposal in Allegheny County. Students obtained statistics on disposal by analyzing time trends in sales and life times; collected data on current practices of reuse, resale, scrap processing and landfilling; and presented their analysis and recommendations to a panel including the Allegheny County commissioners and representatives of local industries. Several manuals have been developed to aid faculty and students in the process of teaching and learning this course.

The Rapid Design course, first offered in Spring 1996, is an interdisciplinary course taught in conjunction with a current NSF grant on the rapid design and manufacture of parts through the transformation of virtual prototypes into physical prototypes. The class, taught by faculty from engineering and computer science, is a sophomore-level, interdisciplinary design course. This past semester, the students designed and built prototypes for an exhibition on mechanisms for the Carnegie Science Center. In the process, the students taught each other about the latest rapid manufacturing technologies, learned about how children learn science, tested an experimental simulation-based design tool, and were part of the process of discovery through participation in a research project.

2. Independent research by students throughout their academic career

Students at Carnegie Mellon can engage in independent research throughout their academic careers. Students at all levels participate in research through regular academic courses in addition to independent studies, senior honors programs, and internships. For example, in the Biochemistry Lab course, the instructor elicits from research scientists in Biology and Chemistry small original research subproblems in their current research projects that can be solved by the students in the lab. In this course, students have produced cell clones tailored with properties required by the researcher.

In 1989, the University also launched the Undergraduate Research Initiative. Through independent exploration, students are encouraged to define their own projects, to work in teams, and to cross disciplinary boundaries. Emphasizing science and engineering projects, the Initiative has awarded research grants to over 800 undergraduates in the past six years. The Initiative also supports students presenting work at conferences, advises undergraduates on every aspect of the research process, and sponsors an annual Undergraduate Research Symposium. This year, over 100 science and engineering students participated in the Research Symposium. Recent undergraduate research projects include: “Eye Development in *Drosophila melanogaster*: A Study with Video Microscopy,” “Analyzing the Effects of Urban Air Pollutants on a Limestone Structure,” “Genetic Evolution of Neural Network Architectures,” “Synthesis, Structure and Magnetic Properties of FeCo Alloy Nanocrystals,” and “Photoelastic Analysis of Load Distribution Patterns on the Femur.”

Current research is integrated into several science and technology core courses for humanities and fine arts majors. For example, students examine the latest research and current problems in the area of environmental science in a course on Science and Technology for the Environment (a core science course for humanities, social sciences and fine arts majors). One of the exercises uses the method of life cycle analysis to compare the environmental effects of consumer products. Thus students (most of them not majoring in science or engineering) use recent environmental research a problem useful for everyday decision making. Further, students in this class practice interdisciplinary teamwork and learning.

3. Facilitation of classroom learning

The establishment of the University Teaching Center and the Center for Innovation in Learning has accelerated the trend of incorporating research into the classroom. While each center has distinct goals, together they have been instrumental in enabling the faculty to improve their classes by incorporating innovations in educational research and technology.

The Teaching Center, established in 1982, assists faculty and graduate students in all aspects of teaching from curriculum design to pedagogy and classroom evaluation. The Center gives faculty access to the latest educational research and a forum to share educational experiences without regard to department or college boundaries. Each semester, the Center holds a series of lunchtime discussions, organized around a theme, to which all University faculty are invited. Some themes from recent semesters are: "Understanding and Fostering Creative Work," "Examining How and Why Faculty Use Collaboration in Their Teaching," and "What Are Experts' Problem Solving Skills and How Can We Teach Them?" At these luncheons, faculty from science, engineering, humanities, business, and fine arts learn effective teaching methods from each other. The Center has become a national model for its programs for teaching support.

Established by the University in 1984, what is now the Center for Innovation in Learning (CIL) has pioneered curricula in hands-on learning in disciplines such as physics and mathematics and has facilitated faculty research on education. CIL improves education on campus by applying modern technology and modern cognitive science to instructional problems. For example, a recent project developed a revolutionary curriculum for teaching electricity and magnetism, which has been well received by students and faculty. CIL also developed cT, a multiplatform language for programming simulations for the science classroom. Through CIL, the University funds fellowships to aid faculty members in carrying out educational projects.

Summary

Carnegie Mellon has invested heavily in hands-on education through the creation and funding of centers and programs that enable students to participate actively in research as an integral part of their undergraduate education. Over the last 10 years, the Carnegie Mellon administration has invested over ten million dollars in these centers and programs, leveraged by grants from federal and private sources. Another important University investment is the commitment to support faculty who work across disciplinary boundaries and who devote time to undergraduate education. Supervising undergraduates in independent research projects, creating interdepartmental courses in which students participate in research projects, and developing new undergraduate courses that integrate the latest research topics are time-consuming activities for the faculty. Without the support of the administration — from the president, to the deans, to the department heads — the faculty would be unable to innovate continuously both the content and the delivery of their courses.