A Project-Based Pedagogy for First Year College Students in Imaging Science

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Abstract - The Chester F. Carlson Center for Imaging Science (CIS) at the Rochester Institute of Technology (RIT) has completely abandoned its traditional lecture-based pedagogy for incoming freshmen, and in its place implemented a radically different project-based curriculum for all first year students. With this new approach, all first year students work together as a single integrated multidisciplinary team for a full academic year to design, develop, build, and test a unique, fully functional imaging system. The goal in implementing this approach is to provide the students with a foundational experience that is more relevant, more engaging, more challenging, and more motivating than the pedagogy that has been used to date. If successful, the impact of this approach on undergraduate STEM (Science, Technology, Engineering, and Mathematics) education could be transformational. It could change long-held perceptions about the abilities of first year students, and could lead to a new understanding of the role of faculty in technical undergraduate degree programs.

Index Terms – Project-based learning, STEM pedagogy, undergraduate education.

BACKGROUND AND MOTIVATION

I. Imaging Science

The reliance of modern scientific and engineering research on imaging techniques has created the need for a new generation of scientists who can not only design and develop the optical systems, electronics, sensors, image processing algorithms, and integrated imaging systems of the future, but who can apply those systems to answer fundamental questions about ourselves and our universe, monitor and protect our environment, help keep our nation secure, and improve our medical care. The science of imaging encompasses a very wide range of subject areas, from the physics of optics and radiation sources, to the mathematics of statistics and topology, to the chemistry of materials, to the engineering of sensors, to the computer science of data mining, to the brain science of vision, to the psychophysics of perception. Imaging science addresses questions about every aspect of systems and techniques that are used to create, perceive, analyze, optimize and learn from images.

Twenty years ago, the Rochester Institute of Technology recognized the importance of imaging to a vast array of scientific endeavors and created the interdisciplinary Chester F. Carlson Center for Imaging Science and its associated degree programs in Imaging Science – the BS program which gives students a common foundation across all elements of the imaging chain, the MS program which prepares graduates for leadership positions in the imaging industry, and the PhD program which produces world class researchers in specific aspects or applications of imaging science.

II. Motivation for Pedagogical Change

The ongoing challenge for Imaging Science faculty is to deliver consistently relevant educational experiences and content in a field constantly evolving during the time it takes for a typical student to earn a degree. Many of the key foundational concepts which were taught to students just a decade ago are no longer relevant as imaging systems based on photochemistry became obsolete and those based on digital technologies emerged. At the same time, many of the students who enroll in the BS program start their studies with a working knowledge of both hardware and software aspects of imaging devices. So the Imaging Science faculty struggle not only to maintain a curriculum which keeps pace with an extremely dynamic field of study, but they are also challenged to employ a pedagogy which aligns with the expectations and prior experiences of their students.

It became clear in early 2010 that the traditional lecture/laboratory pedagogy used in the Imaging Science undergraduate program was no longer effective. Consensus of the faculty was that first year students were not being adequately prepared for upper level courses. A number of employers indicated that recent graduates lacked some of the basic skills and knowledge needed to succeed in the field. And feedback from students indicated a general lack of motivation and enthusiasm for their coursework. The situation prompted the department leadership to approve a radical change to the undergraduate program, particularly for the freshman class, with the goal of providing the incoming students with an experience more relevant, more engaging, more challenging, and more motivating than it had been in the past. It was hoped that such a pedagogy would result not only in improved student understanding of foundational concepts, but also in their adoption of the behaviors and practices employed by professionals in the field.
THE NEW PEDAGOGY

I. Theoretical Framework

The theoretical framework for the new first year pedagogy was based on research sponsored by the Association of American Colleges and Universities’ Project Kaleidoscope (PKAL). The themes emerging from PKAL research regarding undergraduate STEM education are clear and consistent:

- Learning should be experiential and steeped in investigation from the very first courses. [1]
- Learning should be personally meaningful for students and faculty, it should make connections to other fields of inquiry, and it should suggest practical applications related to the experience of students. [2]
- Learning should take place in a community where faculty see students as partners in learning, where students collaborate with one another and gain confidence that they succeed, and where institutions support such communities of learners. [3]
- Higher education should produce new frames of understanding by piloting new ideas, tools, and approaches to keep students’ learning on the cutting edge. [4]

Besides these guidelines, the new pedagogy was also built upon other fundamental beliefs. For example: first year students are capable of understanding advanced concepts, and their motivation would be enhanced by giving them more independence and more control over their educational experience.

II. Curriculum Design

In early 2010, the Center for Imaging Science began fullscale development of a new freshman curriculum embodying this pedagogical framework, with the goal of implementing the new approach at the beginning of the 2010-2011 academic year. The result was a year-long (three academic quarters) sequence of courses in which the students would work together as a single integrated multidisciplinary team to design and build a functional imaging device from scratch.

The general type of device would be specified by the department faculty but the students would be responsible for establishing technical performance parameters by assessing the needs of prospective users of their system. Once those performance parameters were established, the students would be responsible for creating their own work breakdown structure, as well as planning and executing the entire design and development effort. The only major milestones would be formal design reviews for external evaluators at the end of the fall and winter quarters, and a public demonstration of the finished product at an annual campus-wide innovation festival at the end of the academic year.

An instructor of record was assigned responsibility for the course but there would be no required textbooks or formal lectures. The students would jointly construct a common understanding of new concepts by researching in the published literature any topics they needed to investigate, and then sharing their interpretations with their classmates. As necessary, they would seek assistance from subject area experts in the faculty and from upper class students.

Scheduled class meetings (two per week for two hours each) would take place in a dedicated 800 square foot laboratory configured specifically for this purpose and available on a 24 hour basis to freshmen enrolled in the course. No other classes would be scheduled in this room.

There would be no quizzes, no tests, and no final exams. Student performance would be assessed on the basis of attitude, effort, and contributions to the group. In an attempt to provide the students with regular feedback on their perceived performance, they would be required to individually meet with the instructor at least once per month. At the end of each quarter formal peer evaluations would be performed, with each student receiving a compilation of the comments made regarding their performance.

The sequence of courses would be required for Imaging Science majors, but in an effort to maximize the authenticity of the experience, freshmen from other degree programs would be allowed to enroll in any or all of the three courses. Students continuing in the course from previous quarters would be responsible for orienting and integrating any new students into the design team. Although interaction with upper class students was encouraged, formal enrollment in the course was restricted to only first year students.

Since one of the desired outcomes from this pedagogy was to have the students adopt the behaviors of professional scientists and engineers, particular attention would be given to highlighting opportunities for the students to share their experiences with a variety of audiences in both oral and written formats. A faculty member from RIT’s College of Liberal Arts would be recruited to help align the curriculum in the freshman writing seminar with the students’ experiences in the Imaging Science class.

Because this pedagogy represented such a radical departure from any the department had previously used, an external evaluation team from the University of Rochester’s Warner Graduate School of Education and Human Development would be enlisted to formally assess its effectiveness. This evaluation team would be involved in all aspects of planning the new approach prior to its implementation and would collect extensive survey and observational data throughout the year.

PROGRESS TO DATE

I. The Technical Challenge

The 2010 incoming Imaging Science freshmen were given the task of designing and building a device to create a special class of interactive digital images known as polynomial texture maps (PTM). PTMs are unique in that they allow the viewer to manipulate the image in real time so as to render the subject as if it were illuminated from any
arbitrary angle. The technology was pioneered by HP Laboratories in 2001, and has since been widely used by researchers and conservators who are characterizing and preserving artifacts of historical significance. The technology is being evaluated for its applicability to a number of other fields.

A PTM device was chosen as the basis of the freshman imaging project for a number of reasons. Designing such a system would require the students to be exposed to all elements of the imaging chain, including both hardware and software. It was believed that a functioning device could be built at a reasonable cost and with a high probability of success in the time allotted. And although it was a technology which already has an active community of users and developers with whom the students could interact, it was still novel enough that the students felt as if they were working on the cutting edge of imaging science. To further convince them of the significance of their work, they were challenged to advance the current state of the art by designing a system that creates multispectral PTMs going beyond the visible range into both ultraviolet and infrared portions of the electromagnetic spectrum.

II. Early Conceptual Development

The class started in the fall of 2010 with six students, all declared Imaging Science majors. One of the first tasks they were asked to undertake was a simple “proof-of-concept” demonstration of a PTM device using equipment already available in their lab, as well as image processing software written by HP researchers and made available to PTM developers on their web site. Within a single two-hour class period the students successfully created a PTM which, although crude and clearly not optimized for any particular application, gave them the confidence that they were up to the technical challenge they had been given.

Over the next several weeks the students researched a number of foundational concepts in systems engineering, including requirements definition, work breakdown structures, development testing, interface control, and configuration management. They also undertook an extensive “equipment survey” of the hardware and software tools available in the department which might be of use in their development effort. These exercises served to familiarize the students with best practices used in technical design projects, and to introduce them to the resources they would need to tap into to move their effort forward.

Much of the work during the first quarter involved interaction with prospective users of their device. They had face-to-face meetings with representatives from the Early Manuscripts Electronic Library, Cultural Heritage Imaging, and the Library of Congress. They also arranged for an hourlong video conference with the HP scientist who pioneered the development of PTM technology.

As a result of their research and interactions with prospective users the students decided to pursue a “spiral” approach to the development of their system. Their first time around the spiral involved establishing requirements for a “generic” PTM device which captures white light images. Designing and building this “Phase I” system would give them the experience they need to confidently update their requirements for a specific application (they chose to focus on PTM imaging of historical documents) and build a more capable and sophisticated multispectral system. They developed a work breakdown structure to organize their efforts and established plans which reflected their approach.

The freshmen capped off the fall quarter with a formal “Preliminary Design Review” in which several of RIT’s senior administrators evaluated their progress and assessed their readiness to proceed with the next stage of development. The students received a favorable evaluation of their efforts and were directed to proceed.

While formulating their plans and preparing for the Preliminary Design Review the six freshmen realized that this project would require skills that none of them currently possessed. Recognizing that they would need to learn many of these skills themselves, they also decided to try to augment their group with other freshmen who could quickly fill any gaps in the team’s abilities. Their recruiting efforts paid off with the addition of nine new students in the winter quarter. The new freshmen came from a variety of majors, including Mechanical Engineering, Game Design, Biomedical Photography, and Civil Engineering Technology, as well as students who decided to change their

III. Building the Phase 1 System

At the Preliminary Design Review, the students indicated that they intended to have their Phase I “generic” PTM device built and tested by the end of the winter quarter. However they underestimated the impact that the transition from fall to winter and the integration of new students would have on their plans. They also underestimated the number of technical alternatives that would have to be evaluated before they could settle on a suitable design for some of the key elements of the device, such as the illumination subsystem. So although they had begun to procure hardware, develop code, and conduct some preliminary trade off studies, halfway through the 10-week winter quarter the group realized that they had fallen behind schedule.

In spite of this the students continued to make significant progress. Some of the progress came in the form of a deeper understanding of the technical challenges associated with their design and the need to approach the resolution of issues in a logical and methodical manner. Some of the progress came in the form of mastery of key concepts or procedures, such as how to quantitatively characterize an imaging system or measure the spectral properties of light. And some of the progress came in the form of classroom procedures they developed and implemented to more effectively share information and coordinate activities among the various work breakdown structure groups.

Throughout the winter quarter the students continued to give presentations about their project to audiences of their peers. Specifically they gave talks at the weekly College of
Science research seminar, and at meetings of the student chapters of the American Society of Mechanical Engineers, and the Society of Imaging Science and Technology.

So while the students didn’t achieve their intermediate goal of having the Phase I device built by the end of the winter quarter they did make enough progress to feel confident that they would be able to complete this task within the first two weeks of the spring. Their “Critical Design Review” was well received and they were encouraged by the reviewers to proceed with their plan.

IV. Current Status

While the team is still behind schedule their progress to date is impressive. They have designed and built the aluminum framework for their device. They have exhaustively characterized the camera that will capture the individual images which will be processed into a final PTM. They have evaluated the radiometric and thermal properties of several possible sources of illumination, including light emitting diodes (LED), and incandescent and halogen bulbs, and have identified which source is most suitable for the Phase I system. They have developed a computer interface for the system, and have automated control of the camera. They are in the process of developing alternative image processing algorithms to model pixel appearance more accurately than the polynomial approximation used by the HP scientists who originally pioneered PTM technology. They have begun to think about their Phase II multispectral system, and are conducting a Pugh analysis of several conceptual designs. And they have provided a program orientation to the two new students who recently joined the team at the beginning of the spring quarter. In summary, they have entered the final third of their project with pride in their accomplishments and with confidence in the future.

CONCLUSIONS

Although the first year of the new freshman pedagogy has not yet been completed, and a formal evaluation of its effectiveness is still months away, it is very apparent that it is already having a profound effect on the Imaging Science faculty and students.

Since the students are now being exposed to concepts one to two years sooner than they have been in the past, the new approach is having a ripple effect throughout the entire Imaging Science curriculum. This effect has been the primary topic of discussion at recent meetings of the department’s undergraduate curriculum committee. Most of the upper class laboratory courses will have to be restructured to account for the fact that these freshmen have adopted an orientation toward research and inquiry that is significantly more mature and professional than that of previous students. In fact, the new freshmen are so advanced as compared to the department’s upper class students that in many cases they are not perceived as freshmen. One faculty member was recently heard to say “I have to keep reminding myself that they’re less than a year out of high school.”

Beyond their orientation toward research and inquiry, and beyond the knowledge and skills which they have acquired in the past six months, the most remarkable effect of the new pedagogy on the freshmen has been the way it has already enculturated them into the community of scientists and engineers. The success of this enculturation is evidenced by the fact that many of the students are now exhibiting the behaviors used by professionals in the field. Not only are these freshmen communicating and collaborating with multidisciplinary communities of their peers (one recently secured his own opportunity to speak to an entire physics department at a small college in St. Louis), they are also developing their own research projects and are successfully competing for the resources they need to pursue them. Out of the current class of 15 students, three have already applied for and received funding for summer research. Two others have proposals pending. Three more are investigating summer internships or opportunities with Imaging Science alumni near their hometowns.

Can these behaviors in fact be attributed to the new pedagogy being used by the Imaging Science department? Or is this just a uniquely talented group of students? After only six months it is still too soon to tell. But given the apparent early successes of this approach the Imaging Science department has committed to using it again with the freshmen arriving in the fall of 2011.

REFERENCES


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