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Teaching and learning innovation and invention

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Each quarter at Rochester Institute of Technology (RIT), our course on innovation and invention gathers undergraduate and graduate students from as many disciplines as possible and attempts to do something none of us (including the instructors) knows how to do. Our methodology, modeled after business startups more than traditional academic courses, produces interesting inventions and remarkable learning experiences. We will report on the first four offerings of this course at RIT, and speculate on why it works as well as it does. Class begins by presenting students with a stimulating but vague challenge that can engage all the participants (e.g., "build a multi-person multimedia computer that surrounds people") and then mapping and connecting students' interests and expertise. Sub-projects form, develop, die and/or expand, through student collaboration and peer problem solving, as the class pushes toward an ultimate deliverable in which all participants can feel ownership and pride.

Relatively unstructured and unpredictable multidisciplinary problem solving experiences can complement traditionally structured and predictable intra-disciplinary curricula. By collaborating across disciplines, students can deepen their understanding and broaden the application of hard-won discipline-specific knowledge and expertise. They can also learn to enjoy and endure the fine art of improvisational innovation and invention.

Introduction

Although it is unlike any course we have offered previously, we have now taught our course, Innovation and Invention, four times at Rochester Institute of Technology (RIT). It seems to be working: many students learn to innovate, invent, and improvise, and successive classes have had an increasingly large impact on an institution transforming itself into an "innovation university." In this paper we describe what we do, speculate on how it works, and discuss unresolved issues and challenges. Because our assessment plan is in the developmental stages, this paper is an attempt to describe and interpret an ongoing experiment.

Background

The idea for the course originated with the first author, a biological-psychologist-turned-entrepreneur-turned-academic-information-technologist, who felt that his transdisciplinary marketplace experiences with emerging technologies were not reflected in existing course offerings at RIT.

Most schools like RIT transmit state of the art *intra*-disciplinary technical knowledge to receptive students. Most students matriculate out of high school into departments organized around established disciplines, in specialized classes appropriate to their anticipated majors. Unfortunately, this common and traditional pattern of education is at odds with obvious facts about modern life.

First, "eternal truths" aren't what they used to be. As the pace of change increases, the shelf life of technical facts decreases. And the pace of change, especially in technological disciplines, is accelerating at ever-faster rates.

Second, innovation, invention, and creativity thrive on disciplinary diversity and collaboration, and starve without it (Kelley and Littman 2001, 2005; Johansson 2004). Yet "academia rewards depth, [and] expertise is bred by experts who work with their own kind" (Negroponte 2003).

Third, the typical classroom reinforces the increasingly unhelpful notion that knowledge is received from the knowledgeable few. In fact, most knowledge, especially technical knowledge, originates with curious, intelligent, and resourceful innovators and inventors, who are often motivated by the "joy of finding things out" (Feynman 2005/1999) and the challenge of doing and learning things that have not already been done or learned.

Accordingly, the original plan for this course included two components (see Figure 1). There was to be a series of lectures and readings on the co-evolution of humans and technology. And secondly, the professor planned to help students do something that none of us, including the professor, knew how to do.

In fact, however, the second component rapidly overshadowed the former as interests, ideas, and learning opportunities took up all of our time and enthusiasm (see Figure 1). The professor did much less teaching, and the students seemed to do more learning. Each class has produced a remarkable assortment of innovations and inventions, some of which are described below. We are now beginning to think that that by attempting to improvise a course on innovation and invention, we may have developed a methodology for innovation, invention, and education through improvisation. We see it as a promising complement to conventional intradisciplinary education, but not an alternative, for it relies heavily on the expertise our students acquire in more conventional classroom settings, redresses some of the shortcomings of conventional education, and motivates students to acquire, apply, and create both intradisciplinary and interdisciplinary knowledge.

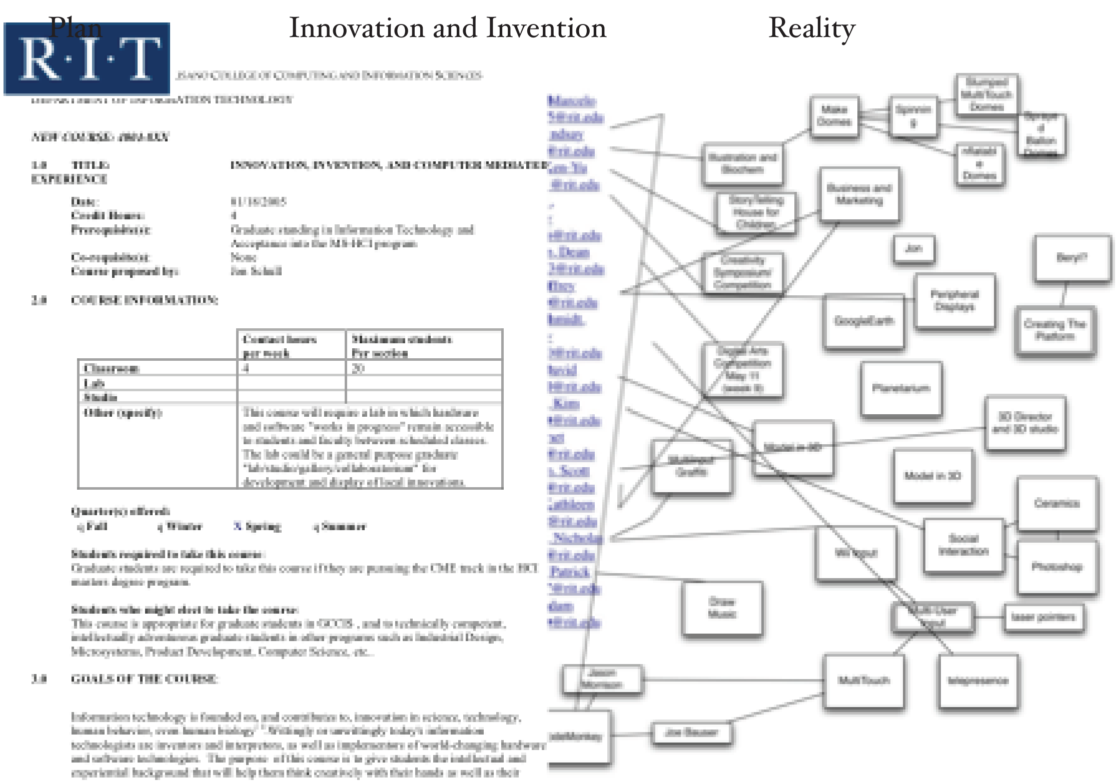


Figure 1. A comparison of the syllabus envisioned for the course (left), with an example of actual practice from the first class of the Spring 06 quarter (right)

Thus, while we are not sure we know how to "teach" innovation and invention (c.f., Leritz and Mumford 2004), we do think we may have a recipe for creating conditions in which it can be learned. We will now describe our practices and speculate on how they work, in the hope that our approach can be evaluated or adopted by others.

As discussed below, one challenge to evaluation and replication lies in the fact that individual students take different roles in the class, representing different parts of the innovation process, and that our guidance of each student is often customized to the individual and the problem at hand. Another challenge lies in the fact that the class is different each quarter. But such challenges go with the territory. We think it is territory worth exploring, and documenting.

Practices

Figure 2 provides an overview of the practices we will discuss.

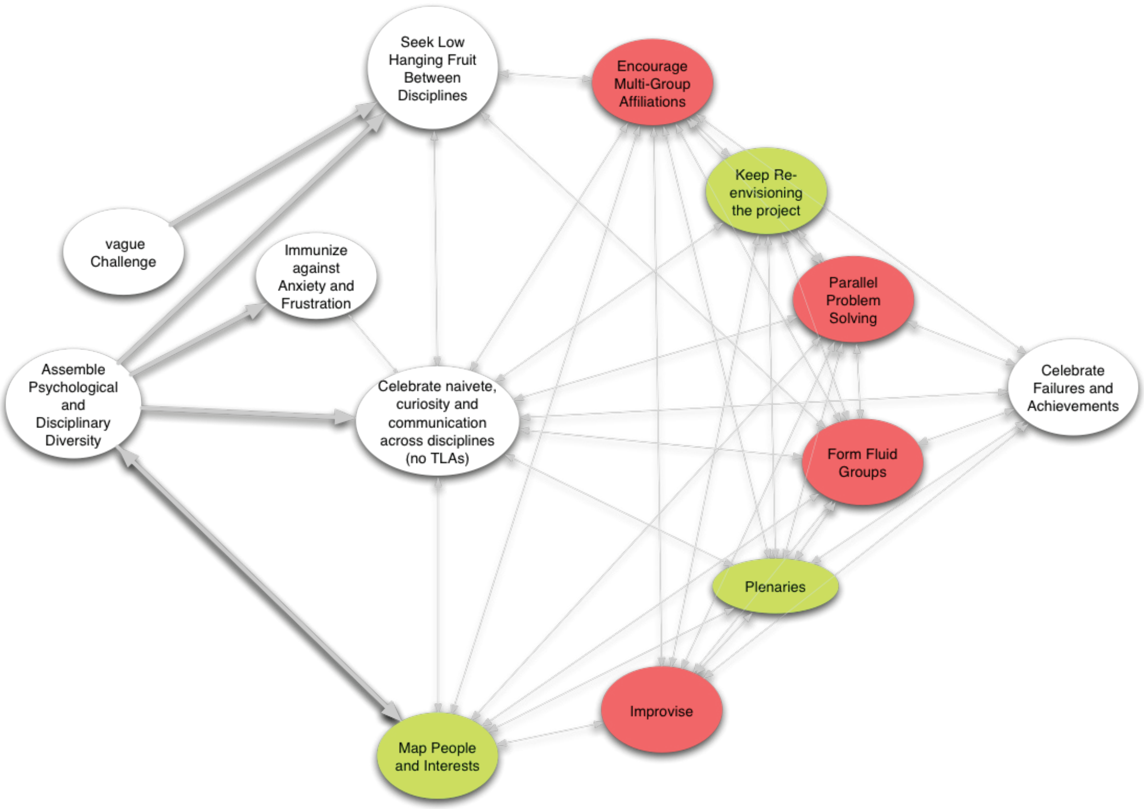


Figure 2. An overview of the key practices used in our course on Innovation and Invention

First, get a multidisciplinary group of adventurous and uninhibited students, and forage among the low-hanging fruit

In a blurb for the book *Ten Faces of Innovation* (Kelley 2005), innovation management guru Tom Peters writes, "A consensus is emerging that innovation must become every firm's Job One; Hurdle One, however, is a doozer: establishing a culture of innovation." He goes on to recommend a thoroughly original and thoroughly tested approach to creating a culture of innovation based on the practices of the leading high-tech design firm, IDEO. *Ten Faces of Innovation* prescribes that diverse teams of individuals with particular styles of interaction be empowered to collaborate creatively. The ten personas comprise three "Learning Personas," three "Organizing Personas," and four "Building Personas" (see Table 1).

Learning Personas	Organizing Personas	Building Personas
Anthropologist	Hurdler	Architect
Experimenter	Collaborator	Set Designer
Cross-Pollinator	Director	Story Teller
		Care Giver

Table 1. Tom Kelley's personas

It is interesting to note that while diverse yet technologically savvy groups like this are hard to create in the corporate world, they are commonplaceóbut literally sequestered at technical universities. By bringing together students representative of these disciplines as well as psychological styles, we build teams with diverse "hard skills" as well as "soft skills." We believe this diversity makes innovation and invention easier than it would be in more homogenous intradisciplinary classes (see Figure 3) because our students find themselves closer to *terra incognita*. (c.f., Johansson 2004).

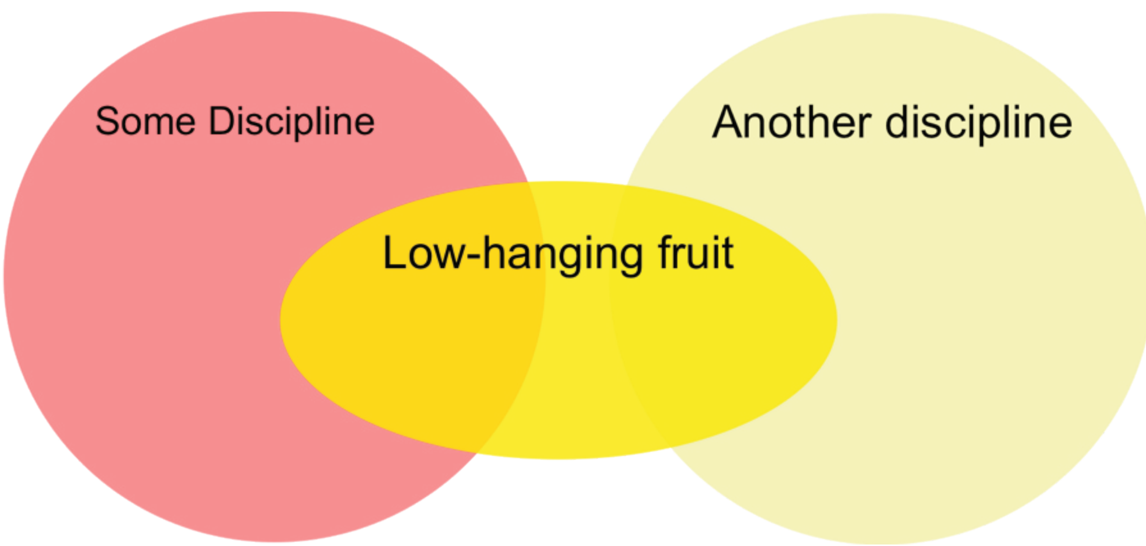


Figure 3. Low-hanging fruit are more common between disciplines

It often takes a novice many years to reach an established discipline's frontiers of knowledge. By the time they do, they will often have acquired habits of thought and expectations that discourage breakthrough discoveries. In contrast, by encouraging "journeyman" students from different disciplines to find areas of synergy between their respective disciplines, it is easy to come up with fun, novel, and promising ideas for projects that none of us are individually qualified to complete, but which small cross-disciplinary teams might well be able to pull off.

Our course is therefore marketed across campus, without specific prerequisites, to "advanced and adventurous undergraduates from all disciplines." The flyer shown in Figure 4 illustrates our marketing efforts and the evolving nature of our practice. The course was originally intended as a graduate course, but enrollment was so low in our first offering that we admitted several advanced undergraduates. Because the undergraduates contributed and benefitted no less than the graduate students, we subsequently created a course number to attract and accommodate undergraduates as well. We all meet in the same time, place (and moshpit). This current quarter, we have attempted to expand our reach further by encouraging honors freshmen to enroll in the class. Our impression is that some of these freshmen are among our best students. However, others seem particularly daunted by the unstructured nature of our offering. (One freshmen's final project will be an attempt to correlate personality inventories with comfort and performance in our class. This will support our fall 2008 theme on "creating environments for innovation.")

Graduate Course: Innovation and Invention
open to ***any*** RIT Grad student
Fall: 4004-806 Thursdays 10-2
(Advanced undergrads can take 1055-559)
Prof: Jon Schull jis@it.rit.edu 738-6696

Invent your future!

Each quarter we do something we don't know how to do.

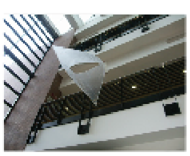
Spring 2006:	Spring 2007:	Fall 2007:
A flying cable-array robotic manta ray mobile for the GCCIS Atrium.	the Immersitorium! An ultralight ultracheap multi-person multimedia immersive projection system. (think World of Warcraft in the round)	Collaboratorium for Multidisciplinary Creativity (and grant money for tools and toys)
		immersive mixed reality studios for hands-on multidisciplinary projects starting with a small auditorium under the library
Subsequently presented in London and Portugal.	Subsequently presented at House of Blues, Disneyworld	*Join the cross campus conspiracy for creative collaboration!*

Figure 4. A flyer advertising the fall 2007 class

In addition to posting flyers around campus, we also market the course in other ways. During the year that the fall course had converted a former auditorium into a mixed-reality studio for multidisciplinary collaboration, we had weekly free-for-all "Open House" evenings. This quarter, we hold weekly town hall meetings, open to the entire RIT community to engage students in planning and design of a new Student Innovation Center. These events, and increasing institutional support for innovation initiatives, have allowed us to increase enrollments and offer the course every quarter.

Begin by discussing a vague but stimulating challenge to which almost anyone can contribute

Each quarter the professors commence with some tentative preconceptions of what the class' collective project might be. Early on day one, we describe those ideas in vague terms (see Table 2).

	Vague challenge	Eventual outcome
Fall 2006-7	"I'd like to make something that challenges the usual notion of information technology as square boxes connected to square screens in square cubicles of square office buildings."	A cable array robotic kinetic sculpture in the form of a gesturally guided, computer-controlled fiberglass manta ray that swooped through the three-story atrium of the College of Computing and Information Sciences. (Ballsun-Stanton and Schull 2006, 2007)
Spring 2006-7	"A multi-person multi-media computer that surrounds you."	An inexpensive immersive computing system in the form of a portable tent-like structure combined with inexpensive computer hardware and software for projecting panoramic animations. (Schull, Cade, Ganskop, and Weill 2007; Hole, Weil, and Schull, 2008)
Fall 2007-8	"A mixed-reality collaboration studio that uses immersive computing technologies to promote multi-disciplinary collaboration."	The collaboRITorium, an innovative classroom environment designed and implemented by the class.
Spring 2007-8	"Something really cool to exhibit at RIT's first innovation festival at the end of the quarter."	A half-dozen inventions and technology demonstrations of novel interfaces and applications developed in the collaboRITorium. (http://opl.cias.rit.edu/inews/articles/collaboration-its-finest)
Fall 2008-9 (in progress)	"Let's design and develop furnishings, technologies, and practices that will ensure that the Student Innovation Center now under construction opens next year filled with student innovations and innovating students."	Our class is leading a series of town hall meetings and charrettes intended to engage the community in planning the interior, the programming, and the software for the Student Innovation Center. (http://Collaboritorium.net)

Table 2. Vague challenges and eventual outcomes

The challenge must be specific enough, yet open enough, to elicit and assimilate contributions from any discipline, and to provide a center of gravity around which a stimulating but discursive opening discussion can orbit. This initial discussion supports and reinforces several key practices we preach.

- Celebrate naïveté, curiosity, and ignorance, no less than intelligence and expertise
- Eschew obfuscation and TLAs (Three Letter Acronyms)
- Collaborate on communicating, communicate to collaborate

We begin our first class session sitting in a circle (even if that requires rearranging the furniture of a typical classroom). The professors describe the vague and provisional class challenge and then moderate a discussion with the students, comparing biographical notes and "cool ideas" while modeling curiosity, freely admitting ignorance, and learning from students, just as students should be learning from each other. (It is probably essential that the professors not fake these attitudes.)

These conversations position our students as domain experts and liaisons to their own disciplines, while redressing a shortcoming of conventional intradisciplinary education, where students are typically a step behind their professors, and encouraged to master and use specialized vocabularies. This training actually hinders communication across disciplines, and over-use of Three Letter Acronyms (TLAs) inìmixed company is a reliable symptom. By articulating the no TLAs rule, we begin to treat the disease. Another practice is to ask students who *don't* understand a technical term to raise their hands to exempt themselves from being asked to explain it. We ask the students who *don't* raise their hands to explain the concept in question; they learn to ask for clarifications when peers talk past them.

The first few classes thus become an opportunity for mutual education, collaboration, and dis-inhibition. Pockets of ignorance and windows of opportunity are identified, and ad hoc teams are tasked with investigating and reporting on promising ideas.

Collaboratively develop and realize the challenge for the course by brainstorming, mapping interests and ideas, coalescing into fluid teams, and iteratively re-envisioning

As the quarter progresses, our focus shifts from generating ideas and enthusiasm toward converging on a shared vision of what we might actually be able to achieve by the end of the quarter.

Our recipe includes a technique we learned from one of our students the first time the course was offered. As ideas and personalities began to emerge and proliferate during brainstorming, he eventually walked up to the whiteboard and began diagramming people and interests as they were articulated. Once a few nodes and arrows were up on the board, people started to connect themselves to existing nodes while adding additional interests.

Eventually, topics and problems of shared interest emerge, and each person is affiliated with more than one problem-team. The inset in the upper the left of Figure 5 (which repeats Figure 1) was made in real time during the first class of fall 2007-8; the one on the right was created two weeks later. These maps continue to evolve and differentiate as the quarter progresses, with some branches withering away, others springing up, and others bifurcating.

Another trend that emerges over the quarter is that groups progress from exploration of possible solutions to testing, implementation, and demonstration of real innovations.

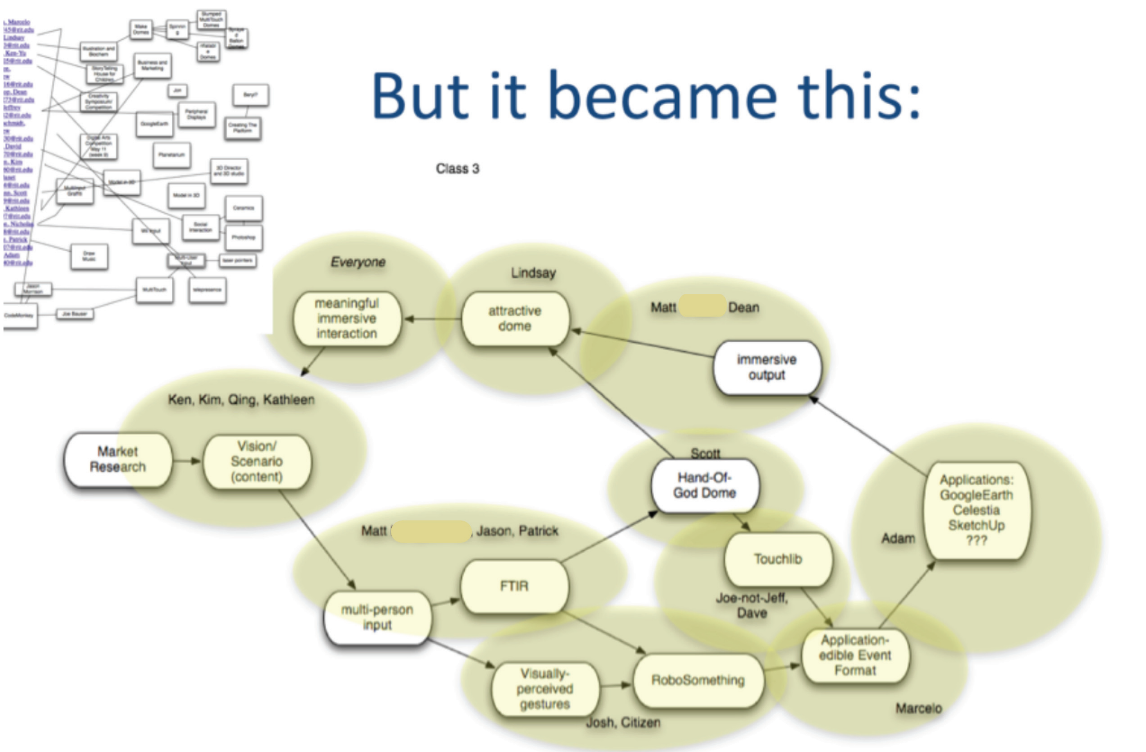


Figure 5. Class vision and coherence evolves over the course of the quarter. (The inset, upper left duplicates Figure 1, "Reality")

Our classroom dynamic also changes as the quarter progresses, with increasing amounts of class time devoted to parallel problem solving by small groups. We call this beehive mode of activity "degenerating into chaos," but in truth, this is when most of the problem solving and collaboration occurs, with individual students gravitating toward problems to which they can contribute, and sharing information across groups. We balance these chaotic periods with ad hoc plenaries during which we rearticulate and re-envision the collective enterprise, and try to ensure that individuals and groups can articulate their role in the ever-evolving vision.

The class' collective oscillation between asynchronous chaos and synchronous plenaries is paralleled by a similar oscillation among individuals, who move from collaborative to solitary activities (such as late-night programming), as the situation warrants.

Diagrams like the one in Figure 6 thus play a critical role in guiding individual and collective efforts toward the moving target of an evolving goal. These diagrams inevitably diverge from reality, but they play a role in our method analogous to that of Gantt charts in project management, and business plans in startups. It is also worth noting that we sometimes fail to come up with a diagram that harmonizes everyoneís activities and anticipated contributions. We take this as symptomatic of the real problem of disharmony.

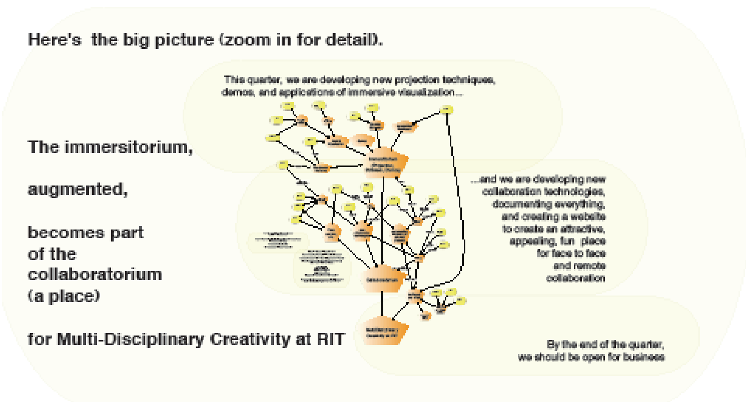


Figure 6 An "emerging vision" diagram from fall 2007

Of course this is *not* traditional project management, nor are we subject to the same constraints as business startups. Our final project, and our path to it, is discovered more than planned, and we do not pretend otherwise. As with business startups in changing environments, opportunity-*finding* is at least as important as problem-*solving*.

Celebrate failures as well as successes, celebrate collective as well as individual achievements

We end each quarter with a series of presentations/demonstrations in which individuals as well as groups present and explain their various contributions, including individually written term papers on topics negotiated between students and professors. Term papers are typically required to combine scholarship with documentation of a sub-project. This allows the professors to appraise and grade individuals, but it also allows students to discover and demonstrate that they have each developed a unique perspective on novel problems. A number of these papers have become published articles or conference presentations and others may be incorporated into anticipated patent filings.

Having sketched the life cycle of a typical eleven-week course, we will now turn to some of the liabilities and challenges in what we are doing.

Challenges

Certain students do not flourish in this setting

As noted previously, chronological age and educational level do not seem to correlate well with student performance or appreciation of our class. Adventurous freshmen with advanced expertise can do well, and contribute much. Beginning Ph.D. students can do poorly because they find the lack of structure unsettling, or because they are unwilling or unable to immerse themselves beyond an already-planned dissertation, or perhaps because they are victims of untempered traditional education.

To immunize our students against the anxiety that comes from open-endedness and uncertainty, we (a) predict it, while describing past successes, (b) remind them of Einstein's famous dictum, "if we knew what we were doing it wouldnít be called research," (c) assure them that their grade comes from quality work, significant contributions, risk taking, flexibility, and "helpful failures" and (d) try to make our environment as benign as possible. But a certain amount of uncertainty and frustration is probably unavoidable. Edison famously observed that "Genius is one percent inspiration and ninety-nine percent perspiration." A more complete model would include exasperation.

We hope and believe that some students who find the class frustrating, bewildering, or anxiety-producing eventually come to realize that they learned a great deal about themselves, about innovation, invention, and group process, and about the subject of their individual term paper. But we know that others just "didnít get it." This course is not for everyone, and we want to get better at selectively attracting the right students. We suspect that personality, motivation, and intelligence are all important determinants of performance and appreciation. But we are just beginning to collect and analyze systematic data.

Certain students need to "unlearn" the best practices of their own discipline

For example, while we cherish and benefit from the expertise of our engineering students, their attention to detail, precision, and professionalism can be an obstacle to innovation. Because our forte is the rapid exploration and exploitation of novel problem spaces, not the reliable production of pre-specified end-products, we often encourage engineering students to "first get it done, then do it right." Sometimes they rise to the challenge; other times, non-engineers who "donít know any better" beat them to a workable solution. (While this can frustrate our engineers, we believe there is a valuable learning experience in here.)

Fluid groups dilute accountability

To maximize knowledge sharing, problem solving and the value of each individual, we typically encourage students to affiliate with more than one fluidly defined group. But this makes it difficult to track the activities of individuals, groups, and classes, and to hold individuals accountable for their commitments. The authors are frankly of mixed minds about this, and we are still debating the relative merits of fluid vs. specifically assigned groups. One practice that seems to help is a week-by-week grid in which students log their achievements for the coming week and their achievements of the past week. But for some of our less-self directed students, for some of less-guidable students, it doesnít help enough.

The need for a tinkerer's lab

The original curriculum proposal for this course said, "Each class will conceive and develop a different 'outside the box' project in a 'tinkerer's lab,' available to all faculty and to other graduate students, where physical as well as software innovations are created and displayed." In fact, our quest for a dedicated cross-institute tinkerer's lab is still unrealized, although our efforts may help shape the programming of the student innovation center now under construction. When we have been able to construct tinkerer's labs in the course of a quarter, it has greatly facilitated and organized our efforts, and enhanced our work products. But this quarter, we were unable to secure a space where projects-in-progress could remain accessible from class to class, and it has greatly impeded our efforts. (On the other hand, this quarter mothered the invention of hardware and software for "chameleon facilities" that could support different purposes and people at different times in a common space, such as the student innovation center.)

Innovation is disruptive and institutions are conservative. It's hard to get there from here

While we are grateful for the support and forbearance of the powers that be at RIT, getting staff and administrators to accommodate our approach is an ongoing challenge. Tinkerer's labs tend to be messy, parallel problem solving tends to be chaotic and unpredictable, and new ways of doing things are hard to establish. Our experience with the CollaboRITorium is instructive. In the fall of 2008 the Educational Technology Center generously gave us control of a small auditorium that was scheduled for conversion into a "technology learning and teaching classroom" the following summer. In ten weeks, the fall Innovation and Invention class created a unique collaboration studio with four wall-sized rear projection screens, video conferencing for remote collaboration and monitoring, a cellphone-based security system that allowed authorized students to unlock the studio any time, day or night, and a number of other clever and useful inventions. For the next two quarters, the course was used by our classes and by a few other adventurous faculty, including one (who had not been involved in the design of the facility) who subsequently wrote an unsolicited testimonial stating that the immersive multi-screen setup helped in teaching about human anatomy and "improved the learning environment in dramatic fashion. I've been at RIT for ~22 years and in teaching nearly 32 years and I cannot remember a time I was more excited about my profession."

Such was our success that the past summer's renovations are incorporating a number of the technologies we developed. But they have also normalized and neatened the facility in such a way that it no longer works as a free-wheeling, messy tinkerer's lab for the chaotic community that helped create it. We are now negotiating temporary time-share in a Computer Science dorm that has a woodshop and an electronics shop, and are struggling to ensure that the Student Innovation Center will be able to accommodate us next fall.

Such struggles go with the territory. We often remind our students of the maxim that it is better to ask forgiveness than to ask permission, but it is better still (and usually harder) to induct coworkers and into what we call "the cross campus conspiracy for creative collaboration." As a result of our increasingly visible efforts, we have become key players in RIT's new president's transformational efforts to turn the Institute into an "innovation university," and have been given an opportunity to help shape the still-uncertain outcome.

Courses like these may not be scalable

Even with two professors managing this class, we doubt that we could responsibly support, mentor, and grade more than twenty-five students in a single course. However, this challenge may be a vestige of the belief that all credit-bearing courses must be supported, mentored and graded by professors. We are increasingly impressed and gratified by the ability of some (admittedly rare) students to lead and direct their nominal peersí activities, and are now trying to ensure that the Student Innovation Center can support extracurricular trans-quarter, multidisciplinary projects and teams that can build upon and contribute to the center's hoped-for culture of collaboration. One function of the Innovation Center may be to help student teams recruit off-campus mentors, partners, and qualified evaluators who can help the students simultaneously get the job done and get academic credit.

Promising projects often die off when the teams and classes that created them disband

Every quarter, we struggle to get fast-moving and fluid teams to document and archive projects so that they can be picked up and extended by successive generations of students and would-be entrepreneurs. We have used wikis, blogs, portfolios, discussion forums, shared documents, google groups, and videotaped final presentations, but so far we have not been able to marshal these emerging technologies to create a "cultural memory" that sustains some of the most interesting ideas that emerge in our classes. A current project this quarter is the development of an "Idea Pool" for the Student Innovation Center (that may be built on top of OpenProjectDatabase.org) into which students can contribute, and out of which they can draw, promising ideas. Interesting and unresolved technical, social, and intellectual property challenges abound.

Assessment is difficult

In this course, students are urged to identify their own strengths, find partners who complement them, and develop a passionate interest and expertise in something they can make their own and to stretch themselves. Learning outcomes and criteria for grades therefore vary from student to student. Nonetheless, our evolving assessment methodology includes the following: we assess creativity and technological literacy through entrance and exit surveys and individual papers, we use final portfolios to assess innovation process, and we use verbal, written, and visual communication to assess ability to communicate across disciplines.

Similarly, although we are attempting in this report to document what we believe is the growing and salutary impact of our course on our students, our colleagues, the Institute and, potentially, on society, this is not a well-controlled scientific experiment. The new president's vision of an innovation university, for example, emerged independently of our prior and ongoing activities. We are supporting and helping to realize that vision, but it is often hard to tell the difference between riding the wave vs. creating the surf.

On the other hand, we are beginning to document a growing portfolio of projects and collaborations that have developed a life of their own.

- Our inexpensive immersive computer system has evolved into a portable cube system, popular at events at RIT and in Rochester, and with many developers earning independent study credit. "Science Cubes" are being developed along with the Center for Imaging Science into a distributable "Science Portal" system for schools, and multi-site collaboration.

- Our idea for a mixed-reality collaboration studio has also shown its worth on campus and has inspired several intramural and extramural grant applications. A successful intramural application resulted in the Technological Learning and Teaching studio described earlier. An NSF SGER grant has allowed us to develop the studio further, and is supporting our efforts to disseminate and further develop our work.
- Several other innovative proofs of concepts: laser and wii-based pointers that function as a remote mouse in immersive environments, presentation software that simplifies the development and control of multi-screen presentations, and a drop dead simple user interface for manipulating three dimensional architectural models by manipulating physical objects are under development.
- As this paper should indicate, several of our social inventions are being incorporated, albeit in fits and jerks, on campus. One such initiative is a year-round collaborative innovation program that now features our course every quarter, along with several others, all oriented around a common problem (this year, "ensuring that the student innovation center is filled with student innovations and innovating students").

Conclusion

Innovation—the successful introduction of new and useful practices—often requires social engineering. Our course, and our way of prosecuting it, is arguably an invention to promote innovation. It is a work in progress, and this paper a preliminary a report from the field.

We do not claim that our method always works, or that it should replace traditional methods. We cannot yet objectively validate or invalidate our own enthusiasms, aspirations, and interpretations of an experiment in which we are, ourselves, immersed. And we know our classes do not meet the needs of all of our students. But we also know that a certain number of students—many, but not all, of our best students—describe it as a uniquely stimulating and valuable opportunity to learn new things in new ways. We hope it also prepares them for a world that will require them to come up with their *own* methods of learning new things in new ways.

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