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Using a Non-Traditional Pedagogy In STEM Disciplines: Implications For Faculty

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**Using A Non-Traditional Pedagogy In Freshman-Level STEM Classes:
Implications For Faculty**

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Abstract

For the past several years educational researchers and national panels have been urging colleges and universities to reform their STEM curricula to make them more relevant and engaging. In an effort to be responsive to this call, the Chester F. Carlson Center for Imaging Science (CIS) at the Rochester Institute of Technology (RIT) has implemented an immersive year-long project-based class to introduce new freshmen to the interdisciplinary field of Imaging Science. With no formal lectures, labs, quizzes, or tests, this class is a radical departure from previous lecture-based introductory courses. Rather than have students simply acquire a foundational body of knowledge, the goal of this approach is enculturation – getting the students to adopt the practices and behaviors of professionals in the field. To date three cohorts have experienced this pedagogy and the initial indications are that it shows great promise. In general, students who have taken the course demonstrate a propensity toward active learning and a greater desire to actively pursue opportunities for research. Even so, class sizes have been relatively small and consequently there is not yet sufficient data to rigorously assess the effectiveness of this pedagogy. However the implications of this approach for the faculty who use it are becoming very clear. This paper provides individuals who may have the opportunity to teach a non-traditional STEM class with valuable insights regarding the attributes which may influence their effectiveness in this environment.

Introduction

For the past several years research on STEM education has consistently revealed the benefits of non-traditional project-based experiences for students at all levels. As a leading sponsor of scholarly work in this area, the Association of American Colleges and Universities' Project Kaleidoscope (PKAL) has been a vocal advocate for widespread STEM education reform. 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]

Responding to the Call: Implementing A New Non-Traditional Pedagogy

In 2010 the Rochester Institute of Technology's (RIT) Chester F. Carlson Center for Imaging Science (CIS) developed and implemented a new freshman-level curriculum embodying this pedagogical framework. The new curriculum is a year-long (three academic quarters) sequence of courses in which the students work together as a single integrated multidisciplinary team to design and build a functional imaging device from scratch.

The general type of device is specified by the department faculty but the students are responsible for establishing technical performance parameters by assessing the needs of prospective users of their system. Once those performance parameters are established, the students are responsible for creating their own work breakdown structure, as well as planning and executing the entire design and development effort. The only major milestones the students are required to meet are two 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 is assigned responsibility for the course but there are no required textbooks or formal lectures. The students jointly construct a common understanding of new concepts by researching in the published literature any topics they need to investigate, and then share their interpretations with their classmates. As necessary, they seek assistance from subject area experts in the faculty, from upper class students, and from outside sources.

Scheduled class meetings (two per week for two hours each) take place in a dedicated 800 square foot laboratory configured specifically for this purpose which is available on a 24 hour basis to freshmen enrolled in the course. No other classes are scheduled in this room. There are no quizzes, tests, or final exams. Student performance is 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 are required to individually meet with the instructor at least once per month. At the end of each quarter formal peer evaluations are performed, with each student receiving a compilation of the ratings and comments made by their classmates regarding their performance.

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

Since one of the primary outcomes from this pedagogy is to have the students adopt the behaviors of professional scientists and engineers, particular attention is given to providing opportunities for the students to share their experiences with a variety of audiences in both written and oral formats. For example while doing their initial research the students compile a collection of written précis which help them construct a common understanding of key technical concepts. Their written products also include requests for purchases of equipment, user's manuals for their systems, and responses to action items raised at the formal design reviews. Those design reviews are the primary oral presentations each quarter, but presentations are also given to a variety of undergraduate student groups such as the Society of Imaging Science and Technology, the Society of Mechanical Engineers, and the College of Science Undergraduate Research Symposium.

While the architects of this new CIS freshman pedagogy wanted it to reflect the most recent research on STEM education, it was also built upon other fundamental beliefs. For example, the belief that first year students are capable of understanding advanced concepts, and their motivation is enhanced by giving them more independence and more control over their educational experience. The CIS team felt strongly that if successful, this pedagogy would be transformational, and would not only challenge widely held perceptions of students' abilities, but also the role of the faculty in undergraduate STEM education.

Results To Date

Because this pedagogy represents such a radical departure from any the department has previously used, it is important to evaluate its effectiveness. To do this, the department initially planned to enlist the aid of external evaluators to conduct a formal assessment. However anticipated funding to support this effort did not materialize, so a rigorous evaluation has not yet been performed. Additionally, the desire to draw any clear conclusions regarding its effectiveness is also hampered by the small sample size. To date, only three cohorts – a total of 64 students including those who are currently enrolled – have taken this class. And since the students from the first cohort are still currently in their junior year of studies, the full impact of this pedagogy on their academic careers cannot yet be fully assessed. More data must be collected and a more comprehensive analysis must be done before any definitive conclusions can be drawn about the effectiveness of this approach.

In spite of this, the department is attempting to identify any early indications in student attitudes and behaviors which may be attributable to this pedagogy. Indeed, some appear to be emerging. For example, student feedback on standard course evaluations and other informal surveys has been overwhelmingly positive. When asked "What is your overall rating of this course?" 75% of the responding students have given it the "best possible rating," another 15% rated it "above average." No students have ever given ratings of "below average" or "worst possible." Representative written comments from these surveys have included statements such as the following:

> *"Due to the interest I had in this class, the collaboration, and the difference in experience from any other course, I wanted to do the work. I wanted to learn. Avoiding the ever-trudging 'learn for the test' class structure, this class made me motivated."*

> *"This class brought me confidence in who I can be and what I can do with my knowledge. My life has been altered for the better and I look forward to all of the opportunities that lay ahead of me because of this experience.*

> *"Not only did I learn more in this class than I did any others, but I was always more willing to learn, to seek out help, to try and solve issues myself, to give my opinion, etc. "*
>
> *"The value of a class such as this shouldn't go unnoticed. More than just basic knowledge, I've grown as a person."*

Aside from these testimonials, there are other indications that this pedagogy is having a transformational impact on students. Most notably, students in the first two cohorts have clearly demonstrated a greater inclination to pursue research opportunities, both on and off campus, when compared to their predecessors. Before their freshman year had ended, multiple students in both of the first two cohorts had written proposals and received funding to undertake independent research projects. Some of these projects have been a continuation of the work done within the Freshman Imaging Project class to extend the capabilities of their system or explore adapting the device to other applications. Other projects involved the development of entirely new systems. Beyond their freshman year a significant number of students are also seeking research experience in one or more of the Center's laboratories, and through co-ops or internships. In general, students who have been exposed to this pedagogy are doing more, and doing it sooner, than those who experienced a traditional lecture/lab pedagogy in their first year.

Implications For Faculty

As a result of the positive reaction to this pedagogy, CIS is now prepared to employ it more broadly at both the undergraduate and graduate levels. Therefore more thought is being given to how to identify the most suitable faculty to lead classes using this approach. This is no small task. While many faculty seek out opportunities to try new and innovative pedagogies, this is not always the case. Some faculty freely admit that they are only comfortable in a traditional lecture-based setting. Charging these individuals with the responsibility for teaching a non-traditional class might result in a negative experience for both the students and the instructor, one which could possibly have long-term consequences for the department. But even those faculty who express a genuine interest in trying their hand at a non-traditional course would be well advised to reflect on their abilities in each of the following areas before committing to teach using this pedagogy:

- **Ability to work with uncertainty**

For many college faculty the teaching experience involves following a detailed syllabus which describes from day to day precisely what topics should be presented in a lecture format in order to cover the required content within a single academic term. For many that content rarely changes – the list of topics always has been, and always will be, the same. Usually these individuals know well in advance precisely what they are going to say when they present the material. In some cases they can even anticipate what questions they will be asked, and it's very likely they already know how they will respond. They are rarely surprised by anything that happens in class. Teaching for these faculty members is a very predictable routine.

This is not the case for any faculty who choose to use a non-traditional pedagogy like that being employed in CIS. For those individuals, teaching could never be described as predictable or routine. In fact, working in that kind of environment is much like being in a "reality TV" show. From the very first day, those who teach using this approach never know how it's going to play out. A syllabus is of little value. There is no script to follow. Planning is virtually impossible. No one knows what to expect. For some, working in this mode may be unnerving, especially considering that in the CIS model the uncertainty lasts throughout an entire academic year.

- **Ability to constantly adapt**

Since it is impossible to develop detailed lesson plans for classes which follow the CIS model, any faculty member who chooses to teach in this mode must be able to constantly adapt to events in order to most effectively help the students grow and develop as scientists and engineers. Assuming that this teacher truly embraces the belief that the students should be responsible for their own learning and that they should determine the direction the project takes, then that faculty member must be prepared to constantly assess the students' progress on a daily basis and respond as required to help them move forward. This daily assessment can be based on a variety of inputs such as classroom observations, e-mail exchanges, informal discussions, or postings in online forums. Since the students frequently work late into the night in their dedicated laboratory, it is often enlightening to visit the area first thing in the morning. By examining changes to material on the white boards or the equipment on the work benches it is possible to get a sense of how much progress was made overnight while the faculty member was home sleeping. In this way the faculty member can get a sense of the students' current commitment to the project and the rate of progress they are making toward their goals, and can use this daily evaluation to selectively target their interactions with individual students or groups of students to keep them on track.

It is also worth noting that for those who teach a class such as this more than once, not only is it necessary to adapt from day to day; it is also necessary to adapt from year to year. At first this might seem obvious since each year brings a new project and a new set of students. But the CIS experience has shown that it is easy to be lulled into a false sense of security after a few successful years of using this approach. In the case of CIS, the experiences of the first two cohorts seemed very similar in terms of the pace at which group and individual development took place, the way in which students responded to the pedagogy, and the ultimate outcome of the project. However with the third cohort (currently in progress) the experience has had a significantly different "feel" to it. The class has been much slower to evolve as a group, the students have been more reluctant to openly share their thoughts and ideas, and the development of the system is far behind where it has been at this point in the year in previous cohorts. This contrast has been dramatic, and it has clearly illuminated the need for faculty to view each cohort as unique, and although past experience may inform the strategies the instructor uses to motivate and facilitate the group, prior successes are no guarantee of a positive outcome from year to year.

- **Ability to establish an environment in which the students can and do challenge each other without feeling threatened**

In the CIS model, the freshman projects involve the development of sophisticated imaging systems. The first cohort designed and built a device for creating a new class of interactive digital images which allow the viewer to reposition the illumination – after the image has already been taken. The second cohort built a 3D head scanner to help physicians assess a patient's susceptibility to intubation prior to surgery. The current cohort is developing a multi-camera video system which has the ability to keep one element of the scene constantly visible and in focus even when it is obscured by other objects in the field of view. These are extremely ambitious projects. Most people would consider them to be beyond the capabilities of new freshmen. Even so, the CIS experience to date proves that freshmen can and do succeed with such projects.

The key to this success lies in the power of the collective efforts of the students in the class, working together, to solve problems that are beyond the ability of any one of them to solve alone. But just "working together" is not sufficient. If the concept of "working together" means nothing more to the students than breaking down a large problem into smaller problems, or evenly dividing their workload among the group, they may find themselves still coming up short. If, however, "working together" implies collectively challenging each other, asking probing questions, and pushing their classmates to reach deeper levels of understanding, then they will quickly find that no task is beyond their grasp.

Getting freshmen to adopt this perspective on collaboration is not easy. In most cases, when challenged by a classmate with a difficult question their natural reaction is to feel threatened. In the mind of most new college students questions are asked to ascertain how much they know about a given topic. And if their knowledge is shown to be lacking, there are typically repercussions in terms of their grade. So feeling threatened is not unusual. It is the job of the faculty member to help the students get past that feeling and to accept that the motivation behind probing questions in this environment is not to make them look bad, but rather to help the group collectively construct a deeper level of understanding.

- **Ability to relinquish power, and accept all the consequences of doing so**

To a large extent, the ability to establish a non-threatening environment for the students comes from the ability to convince them that they truly own the project, and that they have total unrestricted power to make decisions about all aspects of its execution. This is an entirely new and foreign paradigm for college freshmen. Since they are coming to this class with 12 years of years of experience in which their teachers are placed in positions of power and authority, the students are naturally inclined to continue operating in that mode. Therefore getting them to accept this power takes a considerable amount of time and is extremely difficult to achieve. And yet it is vitally important if one of the primary goals of the course is to have the students adopt the behaviors of professional scientists and engineers.

There are many techniques that the instructor can employ to encourage the students to accept the power which is being given to them. Indeed a thorough discussion of this topic is well beyond the scope of this paper. However it is at least worth noting here that seemingly insignificant factors such as the room configuration, and the positioning of the instructor within the room, can have an enormous impact on how power relations are defined within the group. The instructor should frequently assess those power relations to ensure that to the greatest extent possible the students perceive them as just another colleague collaborating with them on this project, and not someone to direct and judge their efforts.

Once the instructor has succeeded in having the students assume the position of power within the class, it is imperative that they be allowed to exercise it without exception, even if in doing so it becomes obvious that their actions will have an adverse impact on the project. While the faculty member can and should engage the students in a dialog about their use of power to help them analyze options and assess the potential impacts of their actions, once their decisions have been made the instructor must not intervene to prevent them from implementing those decisions. It can be extremely difficult for a faculty member to stand idly by and watch while the students take actions that will clearly move the project in a negative direction. But even greater long-term harm would be done by taking back from the students the power they have assumed, even if it is only temporarily. The faculty member must be willing to let the students make mistakes, and to learn from those mistakes, even at the cost of not completing the project by the end of the year.

- **Ability to deal with situations outside the area of expertise**

Most university faculty are hired precisely because they are recognized experts in a particular discipline. To become an expert, they typically acquire a very deep knowledge limited to a narrow aspect of their chosen field. That depth helps them secure external funding for research, and it serves them well in upper level classes with very experienced students. However that depth can be a detriment when it comes to classes such as the CIS Freshman Imaging Project.

While students in the class will naturally have to deal with technical problems related to the development of their system – problems that the expert instructor may be able to help with – the scope of the issues that will confront these freshmen go well beyond technical challenges. In the past three years the CIS instructors have had one situation in which a male student complained that the women in the class were wearing clothing that was too revealing. A female student felt ostracized by her classmates when she attempted to assume a leadership role in the group. A number of students came to the class with behavioral or physical challenges that required some level of accommodation. Several of the freshmen expressed extreme discomfort about providing honest feedback on peer evaluations. In a traditional classroom setting, the instructor, who likely doesn't have the training or experience to deal with these situations, may not feel comfortable addressing them and might well choose to ignore them. But in a non-traditional environment, where the dynamics of the class have a great impact on how the experience plays out, it is essential that the faculty member engage the students to help them resolve these issues, regardless of their primary field of expertise.

- **Ability to negotiate with other faculty about their role and how to deal with classroom situations**

From the beginning, the CIS Freshman Imaging Project was intended to be a class in which a team of faculty and staff mentors would work together with the students to achieve the technical objectives of the group. This arrangement seemed ideal, since one of the primary goals of the course was the "enculturation" of the students in an effort to draw them into a professional community of practice. So while there is one official instructor of record with central responsibility for administering the course, in fact an extended team of faculty and staff work with the students on a daily basis.

This arrangement affords enormous benefits to the students, since the pool of knowledge and experience they can tap into goes well beyond what any one faculty member could ever offer them. And it also helps the official instructor, who, as mentioned above, may not have the background to address all situations that arise in the class. But this team approach can also pose unique challenges for the instructor of record. For one, some of the other faculty and staff mentors may find it extremely difficult to abandon a traditional classroom paradigm and adopt one which is radically non-traditional. Just as the instructor of record must take action to encourage the students to accept full responsibility for their learning, so too must he or she encourage the mentors to allow the students to do so. Mentors who cannot embrace this paradigm will quickly derail student progress toward adopting the desired behaviors and practices.

The instructor of record will also encounter challenges when there is no consensus among the faculty/staff mentors about how to address issues which arise. The way in which the entire mentor group deals with these situations is critical, because not only will it influence the way the students proceed with the project, but also because whether they realize it or not, the mentors are modeling the behaviors they want the students to adopt when it comes to resolving differences and reaching consensus. Consequently, the instructor of record must ensure that in these situations the interactions between the mentors present to the students an example of how professional differences are resolved in a positive and constructive manner.

- **Ability to accommodate the expectations of external stakeholders**

Many entities outside the non-traditional STEM class have a vested interest in its outcome. For example, in CIS the Center's Director, who makes all of the department's budget decisions and who invests heavily in facilities and equipment for the course, expects the experience to influence a positive cultural change within the Center and to motivate a fundamental paradigm shift in STEM education more broadly. The university's Provost expects to use the course to attract students to RIT by showcasing pedagogical innovation across the campus. External partners who represent potential "users" of the systems the students develop often expect access to the finished products or rights to intellectual property. And of course the department's faculty expect the experience to prepare the students for success in their upper level courses.

All of these expectations weigh heavily on the faculty who teach such courses because they also come with an expectation of influence over what happens in the class. Even if they have no first-hand experience using non-traditional pedagogies, all external stakeholders will offer their insights, opinions, and recommendations as to how the class should be run or the technical direction the project should take, and they will expect this advice to be acted upon. When that happens the faculty member responsible for the execution of the class often walks a very fine line. Cultivating and nurturing relationships with external entities is absolutely essential since the involvement of these parties is critical to the success of the class. Failing to acknowledge the importance of this relationship by downplaying or ignoring the advice of the external parties could alienate them and ultimately have a negative impact on the students' experience. It is therefore important for the instructor to recognize that these external partners are valuable resources, and to work closely with them to incorporate their contributions in ways which are consistent with the pedagogical approach used in the class.

- **Ability to be introspective, constantly self-evaluating**

Some educational researchers have asserted that academia is a self-perpetuating culture [5]. The most advanced degrees are granted to students precisely because they have become just like their professors. They act like their professors, think like their professors, and they speak the same "language" as their professors. They do so because for many years they were told that was the only way to succeed in reaching their goal of gaining membership in an exclusive community of practice. And since it is from the ranks of those with the most advanced degrees that the overwhelming number of university instructors is drawn, it is almost inevitable that any faculty member who is tapped to teach a non-traditional course will carry into the assignment the baggage of a deeply ingrained traditional education. For most, that baggage will be very hard to shed.

The faculty member responsible for teaching a class like the CIS Freshman Imaging Project may accept intellectually that using this non-traditional pedagogy can result in significant benefit to the students. However during those difficult times when progress is slow, stress is mounting, and frustration is beginning to take a toll, that same faculty member may let their guard down and unconsciously revert to a more traditional, directive, and authoritative role in the class. This is not unusual. After all, that way of teaching is their norm – that's all they have ever experienced.

So not only does the instructor of record need to monitor the ways in which other faculy and staff mentors are interacting with the students, they also need to closely monitor their own behavior. The faculty who use this approach must constantly reflect on whether they are being "true to the pedagogy" at all times, and if not, immediately take steps to ensure that the students retain the power in the classroom and the autonomy to make their own decisions regarding the direction the project goes.

- **Ability to be "all in," all year long**

Teaching a non-traditional course like the CIS Freshman Imaging Project is difficult. Consider the following:

- The instructor has no textbook, lesson plans, lecture notes, or detailed schedules to work from. Material from previous years is worthless.

- Assessment is next to impossible. Not only are there no tests, quizzes, or finals, there is not even a departmental consensus about what the learning outcomes should be.

- There are no prerequisites for the course, so the students rarely come with any relevant skills.

-The instructor has virtually no say over the composition of the class, which changes every academic term.

- Random visitors – faculty, staff, students, and curious outsiders – wander in and out of the classroom. The instructor rarely knows who is going to show up, what these people are going to do, or how long they are going to stay.

- Not only do the students not know how to do what is being asked of them, no one else in the department knows either.

- The students only earn ½ of the credits that they deserve for the effort they put into the class. Even so, the instructor has to ensure that they stay positive and motivated for the entire academic year.

The prospect of teaching under these conditions may seem daunting, and indeed no faculty member would be advised to undertake this challenge without having a thorough appreciation for the level of commitment that is required to succeed in this environment. Much is demanded of the students in this course. More is demanded of those who teach it. It is essential for the prospective instructor to understand that this is an immersive experience – not just for the students but also for the faculty member. The instructor must commit to being "all in" for the duration of the experience, through the good times and bad, for better or worse, come what may.

Conclusions

As educational researchers and leaders in academia promote STEM education reform non-traditional, project-based pedagogies are becoming more popular at colleges and universities around the country. Those who have rigorously assessed classes employing these pedagogies generally report that they are popular with students and are effective in achieving the desired learning outcomes. It is therefore likely that their use will become more widespread in the coming years. Each new instantiation of a project-based pedagogy will be unique, falling somewhere on a spectrum between a "more traditional" extreme in which the class departs little from a conventional lecture/lab, and a "more radical" extreme in which the students are given total autonomy to determine the scope and direction of the experience. The skills and attributes needed by the faculty who lead each of these instantiations will vary significantly depending on where the class falls on this spectrum.

For classes that fall toward the "more radical" end of the spectrum, such as those in which brand new freshmen are expected to undertake projects comparable in scope and difficulty to many graduate-level projects, the experience of RIT's Center for Imaging Science provides valuable insights for prospective faculty. Although the list of factors provided here has been vetted by those who have actually taught and learned in this environment over the past three years, it is not intended to be all-inclusive. Indeed, the experience of working with freshmen in this type of unique classroom setting for an entire year is too rich and dynamic to capture in a paper such as this. As a single data point it can however inform important decisions at multiple levels regarding the use of similar pedagogies. For department heads the CIS experience should be considered when making the annual teaching assignments for non-traditional classes. For faculty curriculum committees it should influence the extent to which a new pedagogy varies from a conventional class. And for the individual faculty member it should motivate some critical reflection about their own abilities and teaching styles.

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