Adoption of a Non-Lecture Pedagogy in Chemical Engineering: Insights Gained from Observing an Adopter

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Abstract

Promoting the adoption of an alternative pedagogy can be a difficult process. Many professors are not interested in significantly modifying how they teach their course. Those that are interested in pedagogical reform still have concerns that must be addressed before or during an implementation. This paper presents a case study following the stepwise adoption of an alternative pedagogy, with special emphasis on the insights given by the adopting professor. Adoption related literature reveals that data has limited use in convincing people to adopt new technologies or techniques. While the literature also makes it clear that early adopters are in some way disposed towards innovations, our case study indicates that adopters can be developed through a process of awareness building, both of the need for and the process of the innovation.

Introduction

Efforts to bring about system-wide reform in engineering education can be frustratingly slow. While engineering educators continue to churn out new assessments and implementations of alternative pedagogies, as can be seen at the annual ASEE conferences, their efforts have not resulted in wide spread reform and traditional lectures, homework, and tests continue to be the dominant pedagogy in engineering. The question becomes, why does change occur so slowly in spite of an active body of enthusiastic researchers? This paper chronicles a case in which a new adopter was brought into an innovation. The experiences of the new adopter provide some insights that should help inform future research and discussion on implementing new pedagogies in engineering education. We begin by describing why adoption of educational innovations is of interest in engineering education. This is followed by a description of the innovation involved in this study, and some broad background on adoption of innovation in general, with specific focus on education innovations in a higher education setting. We then provide a very brief biographical sketch of the professor brought into the innovation and another, slightly more detailed, description of the innovation as developed and as practiced by the new adopter. Following this is a summary of the assessments used as part of the innovation. The next section details the new adopter's perceptions of the utility of the various assessments and how they pertain to the overall goals of innovation. Finally we provide some reflections on what was learned.

Background on the Problem

The call to more effectively prepare future engineers is ubiquitous (Holmes and Clizbe 1997; Rugarcia, Felder et al. 2000). Central to the call is the failure of traditional pedagogies to meet the challenge. That failure reflects, in part, the failure among educators to attend to research that demonstrates the shortcomings of traditional pedagogies and the opportunities to improve learning provided by new pedagogies that are active, hands-on, and collaborative. More specifically, engineering in the field is active and inductive while engineering in the classroom is passive and deductive (Felder and Silverman 1988; Tobias 1990; Felder 1996). The call to address this mismatch is not new and in the context of rapid global change and challenge, it is increasingly urgent.

Yet the response remains sluggish. Do we need more and better research? Fairweather observes in the National Academies of Sciences commissioned papers report (2009), "NSF and association-funded reforms at the classroom level, however well intentioned, have not led to the hoped for magnitude of change in student learning, retention in the major, and the like *in spite of empirical evidence of effectiveness (Eiseman and Fairweather 1996; Fairweather and Beach 2002, emphasis added)*." More recently, a team of researchers led by the Nobel Prize winning physicist Carl Wieman, speculating that naturally skeptical scientists would be convinced to try new pedagogies if the evidence were available, concluded "research and data on student learning… were seldom compelling enough by themselves to change faculty members' pedagogy"(Wieman, Perkins et al. 2010).

The question then is how can we encourage the adoption of research-based pedagogies? With more than 20 years of research that demonstrates, in particular, the added value of hands-on (HL), active (AL), cooperative (CL), or problem based learning (PL), it has been established in the literature that these innovations can be more effective than having students copy lengthy derivations (Felder 2004). Further, they are more in line with the current needs of industry where engineers work together in diverse, interdisciplinary teams who creatively tackle design problems not found anywhere in standard texts (Varma 2003). If we don't do something we are left with the usual alternative, professor at the front, students in rows facing forward, and only a handful of students really engaged and asking questions or responding to questions from the professor (Nunn 1996), and the ever increasing cry for measurable educational improvement from stakeholders in industry and governments around the globe (Labi 2010).

The concern remains: The country and perhaps the world are graduating insufficient numbers and inadequately prepared scientists and engineers. Life-long learners are needed to face the global challenges and the key role engineers play in meeting those challenges (NAE 2004). Even as NSF, NIH, ABET, AAC&U, and innumerable organizations affiliated with education amplify the call for innovation and change, change remains elusive. If more than 20 years of research and several thousand studies have done little to help faculty supplant or enhance old pedagogies, and research continues to fail to inform or guide practice, then what motivates change among those who do adopt research-based pedagogies, and in turn, what can we learn from those faculty that might be useful in promoting the adoption of pedagogies that are researched-based and are subsequently more likely to help address the challenges facing engineering education in the increasingly urgent broader global context?

Background and History of CHAPL Development

The complex challenge that is outlined above presages our experience with the Washington State University (WSU) Cooperative, Active, Hands-on, Problem-based Learning (CHAPL) approach and its development over the last twelve years. Several studies, presentations, and articles have documented this progression and its impact. These have demonstrated that CHAPL is no less effective at transmitting course concepts than traditional lecture (Golter, Van Wie et al. 2005); students in a CHAPL environment report that it is closer to what they expect their future careers to be like (Golter, Van Wie et al. 2008), and the CHAPL environment can be successfully carried out in a traditional classroom through the use of desktop learning modules (DLMs) (Golter, Van Wie et al. 2006). The CHAPL model itself was not developed absent from the attention to a sizeable body of research, having drawn upon many precursors and examples of active learning pedagogies found, almost always, in isolated pockets of educators throughout science and engineering. For example, DiBiasio (1995) as well as Felder (1994; 1994) have successfully pioneered and have promoted (with limited success) many models of cooperative and/or collaborative learning.

The success of CHAPL components and the extent to which we have embedded each piece of the innovation in a given class has varied over the years as we have assessed, learned, and worked to refine our approach. Though we have satisfied ourselves by a variety of assessments, we have been frustrated by difficulties we have encountered working to parlay the scholarship of teaching and learning undergirding the work, the assessment gains we have demonstrated, or the simple face validity of providing learning opportunities that more nearly mirror the realities of the profession into a model that has influenced a handful of partners to adopt.

Barriers to Pedagogical Innovation Adoption

We're not alone. Change is hard, and the adoption of innovation is tediously or perhaps even perilously slow. Though the specific situation of many adoption research articles are not directly related to education, the general principles of innovation adoption (and the failures) are, according to theorists like Rogers and Shoemaker (1971), related. Rollins (1993) provides a brief summary of adoption and diffusion of innovation research. In Rollin's view, innovators share common traits. He breaks them out:

Early adopters are:

- "Venturesome," "eager to try new ideas," and they are "risky."
- "Respected by peers," regarded as "opinion leaders," and tend to be "more integrated into the local social system."

The early majority:

- "Interact frequently with their peers" and "may deliberate for some time before completely adopting a new idea."
- "Follow with deliberate willingness in adopting innovations, but seldom lead."

The late majority:

- "Adopt new ideas just after the average member of a social system."
- "Are skeptical" and "the pressure of peers is necessary to motivate adoption."

Finally, laggards:

- "Are traditional"
- "Tend to be frankly suspicious of innovations and change agents."

Rollins' model of adopters implies a dispositional element that influences when an individual might adopt an innovation. The dispositional influence is borne out, on a larger scale, in Jippies and Majoor's (2008) study of the cultural influence of rates of adoption of problem based learning in medical education in Europe. There is a demonstrable effect wherein measurable aspects of a country’s culture correlate to rates of adoption of problem based teaching methods within that country.

Locklyer (1992) notes that, with regard to medical innovations, the first step of innovation adoption is to introduce the innovation to the local community of practitioners. Once introduced, the rate of adoption can be affected by the number of ‘independent pieces of information’ available about the innovation, the complexity of the innovation, and the degree to which the innovation departs from normal practice. Lam, et al. (2004) note that the barriers to adoption of evidence based medicine in Hong Kong Include:

1. A mismatch between the evidence-based environment and the teaching environment in which the practitioners learned.
2. The perceived relevance and availability of research, most of which is produced in a different culture.
3. Lack of opportunity to practice
4. Time constraints

Wieman et al (2010) and Hoey and Nault (2002) note the propensity of academics to be skeptical, and the academic culture, they assert, is plagued by “trust issues.” In addition, as Fisher et al. (2003) report, the academic culture upholds a pronounced culture of individual autonomy that they argue also inhibits the spread of innovation. Another contribution is the context that faculty serve many masters (research, service, and teaching) - faculty are busy. Though the need for change and innovation in teaching practice are recognized, and though some have tracked the patterns of how innovation adoption transpires, how and why change happens, when it does, in engineering education remains elusive.

If convincing research does not drive adoption what does? We postulated that a combination of easy to use adoption tools and a broad spectrum of adoption choices combined with convincing research might aid in improving adoption rates. In this context, we follow the case of one early adopter with the goal of developing more focused and ultimately successful strategies for spreading the adoption of powerful teaching innovations.

Methodology

This project follows a very simple case study methodology (Stake, 1978). First recruit an instructor to teach a section of the course in which we have been innovating. Then have the new instructor implement portions of the overall innovation in a manner that builds up to the full innovation, while having an instructor familiar with the innovation teach a parallel section of the course using the full innovation from the beginning. Along the way, observe what the instructor needs and develop tools and materials to ease the process of introducing the innovation.

The Recruited Instructor

Co-author, Prof. David Thiessen (DT) was recruited to assist with the project. He first became aware of CHAPL pedagogies at one of Bernard Van Wie's (BVW's) seminars and was interested in learning more and perhaps trying it out. The innovation made logical sense and matched DTs disposition. He "liked hands-on active learning." It is, he notes, "the way I learn." So being more intentional about providing hands on opportunities, according to DT, "just sounds like a good idea." In addition, he notes, the modules represent something that "you could make" and was clearly something with some additional professional endorsement reflected in the fact that it was a project that BVW had received "funding for."

The CHAPL Course

The blend of innovations DT saw that intrigued him, as described in Golter, Van Wie et al. (2005), includes a pedagogical approach in which the instructor and teaching assistants act as coaches to assist groups in narrowing the discussion focus, probing and guiding groups when misconceptions are encountered and, on occasion, assisting groups in resolving inter-personal conflicts. One of the pedagogical tools central to this approach is the “Jigsaw” or “Expert” group member idea advanced by Aronson *et al (1978)* where students are first split into Home Groups and each team member is assigned a set of concepts relevant to the broad field of either fluid mechanics and/or heat transfer. Immediately after this, new “Jigsaw” teams were formed and comprised of students from each Home Group who share responsibility for a concept. Each Jigsaw team is provided access to a small hands-on module to allow exploration of their concepts. Jigsaw teams are charged with the task of taking two class periods to study concepts embedded within a given module and develop a learning package to take back to their home groups. All of the Jigsaw learning packages are edited by the instructor to assure they are rigorous and appropriate for the activity. After return to their Home Groups each “Expert” has a class period to guide the rest of their group members through the exercises. The entire process occurs once for the fluid mechanics and once for the heat transfer portions of the class. Other textbook problems are given throughout the semester and are representative of the material being learned or which contribute to an important concept or knowledge base not addressed in the hands-on activities. The first half of the semester finishes with two class periods of group work on an open-ended fluid-flow design project intended for expansion to include heat transfer design aspects for two days at the end of the second half of the semester.

Finally, each group presents their project preceding completion, during a following class period, of an exam.

Transition Section—DT Designs and Implements His Own Version of the Innovation

By design, DT's approach was initially a "toe-dip" into group work, as part of an NSF project to develop a transition assimilation package that will take students and professors through a progression in pedagogies by a series of incremental steps.

The first day of class was a traditional lecture in which the Bernoulli equation was derived and an example problem was started. The second class period involved an active learning element in which students worked in groups on different aspects of the example problem begun on the first day of class. Preliminary lecturing was wrapped up at the start of the third class period with a brief review of transport and an explanation of the friction factor as a transport coefficient. Several class periods involved a short lecture (25-30 minutes) on a particular topic followed by a demonstration of the topic.

DT selected to implement take-home quizzes, due at the start of class, and organized his course to include a topic of the day to help students prepare for the in-class activities and discussion. Students worked in groups to record data and fill out the worksheets he developed. The instructor and a senior level undergraduate teaching assistant worked with groups to elicit discussion and try to draw out misconceptions. DT also modeled a series of conceptual questions, relevant to the experiment, which were frequently included in the worksheets. DT maintained a good deal of conventional instructional strategies in his adaptation of the innovation. He included end-of-chapter problems assigned as homework, roughly half for groups and half for individuals.

Several of DT's class periods had the same basic format as the full CHAPL, but the equipment was used in a hands-on mode with groups taking turns with the available Desktop Learning Module or DLM, figure 1 (Golter, Van Wie et al. 2008) which takes advantage of a new low-cost 1ft x 1 ft x 1 ft platform module made to fit on top of a four-legged desk or small table. The modules accept small, see-through interchangeable 5" x 7" fluid mechanics and heat transfer cartridges and are usable in the standard classroom. Because of the plug-and-play modality of the DLM, instructors and students spend little time becoming acquainted with the new equipment and the focus can be on teaching and learning.

Figure 1. Second generation Desktop Learning Module (DLM) with inserted shell and tube heat exchanger cartridge

In addition to developing his own worksheets, DT deviated from the BVW approach by innovating using a convenient aspect of using the DLMs for hands-on work. Since all groups worked with the same cartridge on a given day, DT elected to try to reduce some of the students' confusion, a persistent challenge to innovators who implement "unusual pedagogies," by interspersing short mini-lectures according to his sense of the learning bottlenecks. Having multiple pieces of the same equipment enabled DT to give mini-lectures that would be relevant to the entire class rather than just one group.

The phased implementation culminated after one half a semester in a full CHAPL environment (with team work substituting for the Jigsaw approach). Again this is also the intent of the current NSF project which seeks to develop a set of materials, e.g., the DLMs, and companion guidebook so that a professor can gradually build pedagogical expertise throughout a semester and then settle in on use of a broader set of pedagogical approaches tailored to their personal comfort level. Though not all professors may end up using the full CHAPL design, where all pedagogies are used simultaneously, they will at least become more skilled in the use of a variety of teaching and learning strategies and can effectively weigh their benefits for potential continued classroom implementation.

Finally, each half of the semester ended with a design project, as was done in the CHAPL section. The second half, heat transfer portion, of the semester followed the same format as the full CHAPL section, only differing in that DLMs were used for three of the units (double-pipe, shell-and-tube, and radiator) and, where DLM cartridges are not yet available, dresser-sized modules for two units (fluidized bed and boiler).

Assessment Overview

As noted in the introduction, research based evidence is rarely convincing to promote innovation. There remains the question of how the assessments used in research are viewed by outsiders. Are they considered valid and useful? What might it take to convince a skeptic of the utility of the assessments? The insights provided by DT in his effort to understand the impact of the various aspects of the bundled innovation offer a useful window into the thinking of an outsider in this regard. To capture these insights we held frequent discussions with DT throughout and after the semester. These unstructured discussions were basically just probing conversations aimed at drawing out DT's thinking regarding aspects of the course, the pedagogy, and the assessments we have been using.

To assess student gains in the CHAPL pedagogy, we had been using a mixture of qualitative and quantitative methods. First we used selected questions from an established concept inventory (CI) the Thermal and Transport Sciences Concept Inventory (Streveler, Litzinger et al. 2008) as listed in Table 1. The questions were split into three groups, which were given at different points in the semester in order to measure students' conceptual gains over each topical section of the course.

Table 1

Concepts from the Thermal and Transport Sciences Concept Inventory, which were used in the assessment of our course. The number in each column is the number of questions regarding that concept. Two-part questions were counted as two questions for this purpose.

Concept Name	Pre	Midpoint	Post
Conservation of Mass	1	3	-
Bernoulli Equation including barometric equation	2	6	-
Linear Momentum Conservation	1	2	-
Energy vs. Temperature	3	-	4
Heat vs. Energy	1	-	1

The students were also assigned a series of short writing assignments. These were brief discussions of how the students would approach a design project. For example students were asked to consider designing a piping system for concentrated sulfuric acid and write about what they would need to consider and what equipment they would need, with explanations. These papers were then rated using a content specific adaptation of the well-known WSU Critical Thinking Rubric (Brown 2004; Condon and Kelly-Riley 2004) (see Appendix). Though the writing assignments were given at the beginning, middle, and end of the semester; all of the rating was held until the end to control for time effects on the rating.

Perhaps the most useful assessment we used in this study and in previous efforts is a Flashlight survey asking students to respond to questions asking them to identify the learning strategies and practices they used in the course. The questions were drawn from the Flashlight Item Bank©(The TLTGroup) that are premised on Chickering and Gamson's studies on the principles of good practice (Chickering and Gamson 1987). The principles of good practice in higher education were developed in 1987 and were sponsored by the American Association for Higher Education and the Education Commission of the States. The seven principles encourage: student-faculty contact, cooperation among students, active learning, prompt feedback, time on task, high expectations, and respect for diverse talents and ways of learning.

Unlike student evaluations, discussed in the next section, the focus of the Flashlight survey is not about student satisfaction or even their perceptions of the utility of the teaching. The focus is on what students did during the course to complete course tasks and to learn, and students were asked to compare the innovative course with other courses with which they are familiar. The survey was administered online.

There were 48 questions answered using a five point ‘Likert’ scale, and one question that asked the students to rank five items according to the priority they were given in the course. The results were aggregated to develop a picture of how well the course aligned with each of the principles of best practice.

In addition we collected the written comments from our institution’s standard end of semester course evaluations. By comparing the comments given to the two instructors, we can gain some insight into how well DT’s implementation went. This can help answer whether or not a phased approach is workable.

Results

The Concept Inventories—Mapping Tests to What Matters

Due to confounding issues such as the lack of a true control group, small class sizes and low numbers of questions, the statistics are essentially meaningless. Yet more important than the statistics, DT recognized early a few challenges with the Concept Inventories (CI). First, he noted that the items were sometimes technically flawed. Specifically one of the questions regarding natural convection from a heated cylinder had an answer that was correct only for a vertical orientation; however the cylinder in the problem was oriented horizontally. While this is probably still a sufficient question for students who are beginning this subject, it was extremely off-putting to a subject-matter expert who was used to being concerned about flow in low gravity environments. The CI questions were incongruous with the activities he conducted in the class and with the concepts embodied in the desktop modules. Perhaps because this class is focused on the applied, equipment-focused aspects of Fluid Mechanics and Heat Transfer, as such it focuses more on procedural knowledge rather than conceptual knowledge. Even more importantly, both he and BVW came to believe that the results didn't capture the value-added attributes of the DLMs and the CHAPL innovation. The CI, though rigorously developed (and still being refined) did not adequately map to what either of the faculty in our case most valued. In particular an increased awareness of how the equations the students use tie into the physical reality of the equipment.

The Critical Thinking Rubric—From "Squishy" to Solid Insight

Initially, DT had doubts about the rubric-based assessment method, and the doubts as well as the methodology preceded this study. As DT explained, "It seemed kind of squishy." Moreover, DT's doubts were compounded by the lapse of time across a semester. He felt that the score could be easily influenced by a long delay between ratings which would introduce additional variation in the determination of scores. So DT did a simple experiment, rating one paper multiple times over a few months. He was surprised to find that the scores he ascribed were virtually identical.

Still, like the Concept Inventory, the statistics surrounding the assessment of students' critical thinking were meaningless, for the same reasons.

Both DT and BVW considered the shortcomings of the assessment. It was, again, not really aligned with instruction. The focus on the assessment compromised the focus on instruction. Students were not introduced to the criteria and process. They were not provided rubric or criteria-based feedback from their first analysis, and they were not introduced to the criteria preceding their second analysis. Specifically, they were not provided with structured practice with problem identification, assumption identification and analysis, or instruction in how to marshal evidence and develop and implement solutions. The assessment had been conceptualized *post hoc*, to prove the value of the CHAPL pedagogy, not to learn how to improve it. The realization, DT observed, was not trivial.

Student Perceptions and Principles of Good Practice: What We Test versus What We Measure

In both BVW's and DT's courses, and unlike the Concept Inventory and Critical Thinking assessments, the results were clear and positive. The innovative courses demonstrated exceptional alignment with principles of best practice. For a few select examples of specific questions that demonstrated this across both courses:

- 61% of students agreed or strongly agreed that "I worked harder than I thought I could to meet the instructor's standards or expectations."
- 70% of students agreed or strongly agreed that "I feel comfortable telling the instructor of this course when I disagree with something s/he has said."
- 91% of students agreed or strongly agreed that "I improved at collaborating with peers."

These are indications of high expectations, faculty – student interaction, and inter-student cooperation, respectively.

Though often maligned, DT and BVW both realized not all student self-perception measures are alike. If there had been doubt and differences in perceptions preceding this, DT and BVW agreed that, of all the assessments in this innovation, results in the Flashlight Survey were the least ambiguous. More importantly, they recognized that, though still incomplete, the Flashlight Survey aligned most fully with their own perceptions and observations of students' experience in classes that experienced the innovations. "Our tests," DT observed, "don't really get at it compared to what we see here."

Student Evaluations and Metacognition: The Persistent Challenge

If the Flashlight survey added clarity, the departmental student evaluation instrument stirred old mud. BVW's innovation has been plagued by consistently mediocre evaluations. Though he is the last to deny some merit to students' critique, the persistent complaint contrasts with the Flashlight survey and reveals again the gap between students' cultured expectations and the peril one courts with innovations that require students to change. The consistent complaint BVW receives is that students are frustrated with the expectation that they work together and "too hard for the allotted credits" to "figure things out." At the same time, they consistently praise the course because it mirrors, more than any other course in their curricular experience, the "kind of work we will be asked to do as professional engineers."

Between this rock and hard place, DT's course evaluations, with less emphasis initially on promoting student independence or agency, and though they evince from students the same concern about "too much work," do not obtain the same bi-modal distribution or expressions of indignation.

Insights from DT

When DT first observed the full CHAPL Section taught by BVW, he had mixed feelings. By disposition he is quiet, far from a natural lecturer. As a learner himself, he found observing and doing to be essential—and in no way counter to engaging in hard study. He realized that what he observed was more like what he experiences when he works with engineers in the field rather than the conventional classroom: Groups talking! Nobody standing in front of the group and lecturing, providing answers to questions, as lecture critics have suggested, that had not yet been asked. Rather, what he observed was students engaged in exploring the equipment, figure

2, and wrestling to understand what they were observing as they manipulated the modules—the real time dynamics of heat transfer and fluid mechanics. DT understood that what students were doing was observing and discussing fundamental chemical engineering concepts.

Figure 2. Typical CHAPL classroom, with students gathered around a DLM while the instructor observes and interjects where needed to guide or correct the students' understanding.

In the midst of this ill-structured classroom, and what was intuitive to DT, were what educators have come to recognize as principles of good educational practice (Chickering and Gamson 1987): Students interacting with students; students engaging the challenge with their individual approaches to learning; students engaging diverse ways of knowing; students interacting with the professor; students encountering and wrestling with unusually high expectations; and students in a context in which feedback was rich and rapid.

There is additional research supporting the CHAPL pedagogy, of course, but DT was familiar with articles by Felder and, consistent with Wieman et al, he had much less familiarity in the broader base of educational literature. Felder, DT shares, particularly with his established expertise in the subject and his “practical” orientation, was particularly influential. In the course of sharing the teaching opportunity and designing, later, his own course, DT read more literature, recognizing, he notes, that delving into the literature “makes us realize our ignorance.”

What DT repeatedly notes is that traditional lecture environments, while perfectly functional for transmitting information (Bligh 2000), provide limited opportunities for instructors to observe, guide, and measure the development of students’ learning. By contrast, placing students in a situation where they are expected to learn through discussion, either among themselves or with the instructor, provides the instructor with an opportunity to observe the students thinking, thereby affording the opportunity to gain insights and introduce feedback into the students’ conceptual understanding. This in turn provides the instructor with an opportunity to immediately address conceptual misunderstandings as they arise.

DT also believed that the best way to implement a partial CHAPL was to “step in slowly; wade in.” He says he was “basically lecturing, but also used principles of research design with demonstration of the units rather than at first implementing the hands-on opportunity for students.” He confesses that he was “not convinced with the jigsaw approach.” He saw that group work was effective “for some, the ones who took it seriously,” but he adds, “Only a few really took it seriously,” adding, which is “something that might be corrected by implementation.” Instead, he “liked mini-lectures,” which are often requested by students convinced that somebody needs to tell them what they “need to know.”

DT also was concerned with the lessons students are asked to write in BVW's section. He elected to develop his own worksheets. "You need to re-write what students' developed anyway. Plus "Jigsaws are a logistical nightmare."

BVW's students have consistently expressed difficulty with BVW's conviction and practice that demands students take full responsibility for articulating and answering their own questions, working through difficulties on their own. A very typical quote from student feedback is:

"It needs more lecturing. The group learning is a good idea if it was supplemented with some teaching from the instructor. Without lecturing, like this class, I felt like I was struggling and it felt like I was spending way too much time. Also I wasn't sure all the time if I was approaching and working out problems correctly."

DT elected not to confront this aspect of students' expectations or counter this attribute of the conventional approach to teaching. In his mini-lectures, DT addressed to the whole class from the board when he or they encountered common problems, in effect adopting a just-in-time strategy. For example, a mini-lecture was used to explain how to apply a control-volume analysis to the Venturi meter. At the same time, DT also appreciated and adopted BVW's approach and used the mini-lecture with discretion. It was sometimes more useful, DT felt, not to intervene. Both BVW and DT also adopted group work in their approaches with the additional belief or understanding that it is important for students to assume greater responsibility for their own learning, and the only way to effectively accomplish that is to charge them with responsibility to figure things out for themselves. Both agree that making the determination when to intervene is perhaps "more art than science." As Weinberger observes, “Knowledge is not a result merely of filtering or algorithms. It results from a far more complex process that is social, goal-driven, contextual, and culturally-bound. We get to knowledge — especially "actionable" knowledge — by having desires and curiosity, through plotting and play, by being wrong more often than right, by talking with others and forming social bonds, by applying methods and then backing away from them, by calculation and serendipity, by rationality and intuition, by institutional processes and social roles" (Weinberger 2010).

General Reflections

We have attempted to document the learning curve, expectations and attitudes of *the instructors* involved in order to shed light on the challenges confronting adoption of innovative pedagogy. After having taught their respective sections of the course the two professors reflected on their experiences. As DT reported, implementing the innovation rich transitional CHAPL provided its own compelling arguments and reward for adoption—the opportunity to provide feedback precisely where and when students encountered critical challenges to their learning. Similarly using a rubric initially seen as “squishy” emerged as a method with more solid “anchors” that helped DT understand the extent of students’ understanding with greater consistency than he initially anticipated and subsequently gaining a better understanding of a way to provide additional, richer feedback than had been available to him using traditional grading techniques. These gains are not trivial.

What emerged from the discussions of the results and the challenges in trying to implement an assessment to persuade the adoption of the innovation was the realization that the assessment didn’t adequately convince or persuade us one way or the other. More disconcerting, we realized that much of our focus for the past 10 years has been on using assessment to prove rather than improve.

We realized part of the reason was our perception of the expectation of our granting program managers who we have understood to require such “proof” of increased learning. But in our years of effort, once again reflected in the all too common finding that there was no significant difference between our two groups, we recognized a pressing need for more *useful* models of assessment. We have gained with our assessment some small insight into what students have learned, but we have learned little from the CIs about *how* students have learned in ways that reflect on those components of the CHAPL strategy that are unique. More precisely, we have gleaned from results of either the CIs or the multiple choice questions that have preceded them in our work very little that has helped us refine and improve the way either BVW or now DT have organized the class or approached their teaching. Moreover, the Concept Inventories, with little alignment to the specific activities in which students engaged, were also not particularly valuable for determining the grades of students. The potential value of an objective assessment has been compromised by the problematic reality that students are not likely to provide a representative performance when questions have little context related to the experiences they have had in the class. This, in turn, challenges the utility of the assessment as a measure not only of measuring but for *promoting* learning.

In the course of our deliberations, we realized, too, that the pursuit of *proof* was distracting us from making important refinements in our own course. We reviewed the ongoing challenges we’ve had trying to fulfill grant expectations and the perception that “proof” of the innovation is required, and that such proof is dependent upon “objective” measures like the CI. However, we have never adequately been able to address the perceived need for a suitably large sample size, or to sufficiently control for population variation, pedagogical balance, and all the other attributes of a formal controlled study. Moreover, we also recognized that no aspect of our innovation is without substantial body of research that has already established the veracity of the initiative, and yet that research has done little in helping us promote adoption of all or part of CHAPL with many of our colleagues. Educational evidence has made little headway here or elsewhere. Perhaps the most striking example of this comes from one our own observations, when we asked our faculty subjects of this study if results on the purportedly objective CI were to demonstrate that the lecture was producing significantly better results, would they go back and lecture? When the answer was no, we had to stop and scratch our heads.

We're not the first to observe this, and one landmark study that illustrates this is Lead Center study (Wright, Millar et al. 1998) comparing collaborative learning with lectures. After extensive consideration about what measures would be persuasive for comparing the two pedagogies or treatments, the Wisconsin science faculty involved in the study finally agreed they would not be able to agree. Instead, they decided to conduct double blind interviews with students randomly selected from each treatment. Following interviews with students, faculty overwhelmingly reported that students from the collaborative learning groups outperformed the lecture groups, demonstrating what faculty described as deeper and more flexible understanding of the science. But more to the point of our case, neither the objective tests nor student evaluations used in the study as supplementary measures made the distinction the group of faculty clearly identified. Students in the collaborative learning class were quicker in their ability to recall, more thorough and creative in their ability to apply the information, and more confident in their understanding as well. The point, buried in the study that focused on collaborative learning, was a simple truth most educators know in their hearts—our tests and assessments capture, at best, only a small portion of the learning we most value.

Confirming and disconfirming the general assessment of innovators, DT was, as an "early adopter," by disposition and experience he was prepared to be "venturesome and risky." Though as a quiet researcher he was "respected," he was, counter to the innovation adoption blueprint, more of an outsider to the system. As a professor in the Physics department, though from a Chemical Engineering background, he was probably not fully "integrated into the local social system." In addition, he was probably more aligned with the "early majority." He was clearly deliberative and cautious about moving in, taking only pieces of the innovation and reintegrating with it attributes of the tradition—most notably "mini-lectures."

Still, having chronicled the adoption and placed the subject in the established framework of the literature of adoption, the presenting challenge remains—what have we learned that might help encourage more educators to more systematically adopt the innovation?

For years our team has focused on assessment to persuade adoption. We have demonstrated qualified but usually significant gains in students' understanding of the critical concepts of Chemical Engineering.

Conspicuous in its absence in all of these assessments is attention to learning opportunities that focus on the development of students' metacognition and their understanding of the context in which they are learning. The CHAPL methodology relies on the kinds of collaboration and hands-on application that presages what students will encounter in the engineering profession.

The adoption and the imperative to adopt this kind of innovation are not unrelated. The case we have reported here illustrates the adoption and adaptation of the innovation. The essential ingredients appear to have very little to do with the formal assessments that we have hoped will illustrate the merits of the CHAPL pedagogy. Perhaps the most important attribute of this adoption has been the disposition and the pre-disposition of the incoming faculty. The predisposition influenced his interest and decision to attend workshops on teaching (by Felder and by Angelo) and to find like-minded colleagues in the program who were exploring pedagogies that reflected the principles presented by Felder, Angelo and that are, not incidentally, abundant in the teaching and learning research literature. Most importantly, it has been the opportunity in the implementation of CHAPL to overhear or participate in students' collaboration, which provides insight and opportunity to address students' learning "just in time." DT's understanding of that opportunity and his interest in students' metacognition—how they learn and how they think about their learning—mirrors his own interest, unspoken, in his own metacognition as a researcher, as a life-long learner.

What we have been doing is proving that innovations, which are already proven, work, or like the saying goes, ("rounding up the posse after the rustlers have been caught"—Gary Crooks). The absence of metacognition and lifelong learning in the curricula reflects the misdirection of educational research and our own educational shortcomings having survived, as rarities, mid-20th Century industrial pedagogies ourselves. No more research needs to be done, counter to the running research conclusion. Since it is clear that we need external motivation to rise to the challenges we face in engineering education, it is time for ABET, funding agencies and educational journals to step in and advance their guidelines, similar to what has been done within the new NSF TUES solicitation. Specifically, future research needs to focus on how students and faculty are learning rather than how much they know or how many multiple choice questions they get right. It is not only the opportunity to help students and ourselves learn more on how we learn so that we can do better, it is a focus that will help faculty understand the limits and expansive possibilities of our own learning.

It is clear, from this experience and the literature, that data and well-designed studies are not sufficient in and of themselves to promote adoption of alternative pedagogies. At this point in time, where lectures remain the norm, adopters will be mostly "early adopters." From the literature it appears that a critical mass of adopters is required in order to move on to involving the "early majority". It may be possible to convince more professors of the value of an alternative pedagogy by raising their awareness of the need for and outcomes of the pedagogy. If the trends here are similar to what is seen in medical practice, there will also need to be multiple, independent bodies of evidence that an innovation is being accomplished in order to promote adoption on a larger scale. One possible route to this is convincing professors to experience the innovation in action.

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Appendix – Critical Thinking Rubric for ChE as of Spring 2007

1) Identifies and understands the **problem**.

1	2	3	4	5	6
Cannot identify or understand the problem: "What are you asking for"	Identifies main problem: "This is what he wants us to do."	Understands the Problem: "This is what we need to do, and this is why"	Understands the problem and its implications: "If we did X it might cause Y"	Integrates concepts from other subjects: "We need to consider X, which we learned about in Y"	Full and complete understanding of the problem and its underlying theory: "Sure I can derive that from scratch! (on the back of my napkin in this restaurant without any references)"

2) Identifies and presents the <u>STUDENT'S/Group's OWN</u> **method** as it is important to the solution.

1	2	3	4	5	6
Doesn't know how to begin the problem: "Where do I start"	Approaches the problem by modifying a textbook example: "They did it this way, so if I make these small changes it will work for me."	Background supplies appropriate solution method: "This is how we usually solve this type of problem"	Recognizes problem may be unique: "Does the usual solution method apply?"	Can develop unique solutions from fundamental theory if needed: "If we go back to the fundamentals we can do it this other way."	Can develop a novel method worthy of publication (in a trade or academic journal): "No ones ever tried this before but it should work really well."

Identifies and assesses the key **assumptions**.

1	2	3	4	5	6
Uses equations that look like they might work:	Uses the correct equation: "We used eqn. X because that is what is used for this."	Recognizes the conditions for which an equation was developed and can modify the equation for different assumptions: "Lets add a component for turbulent flow"	Can correctly select assumptions for a system based on an analysis of the physical components: "We have open channel flow, so we can't use a no-slip condition for all surfaces."	Recognizes commonly idealized assumptions and can determine their applicability: "This is the 1% of the time when X doesn't apply."	Knows, from experience, when 20% is close enough. "3.14 is close enough for pi."

3) Assess the **quality of the solution**.

1	2	3	4	5	6
Does not care about the quality of the solution: "Well I got an answer."	Wants the "right answer": "What did you get?" "What does the answer book say?"	Questions physical validity of the solution: "Does my answer make physical sense?" "Is it realistic?"	Understands impact of physical components on the solution and how differing physical portions would impact the solution: "What if the pipe was bigger?"	Understands appropriate application and impact of errors throughout the system: "Well, are measurements are really only so good, so our solution is ……"	Can identify the impact of various fundamental theories upon the problem solution: "If we account for the compressibility it will change in this direction."