Abstract

As part of a larger National Science Foundation grant to Penn State, I ran a special hands-on, “real life” educational program in bioprocessing for senior chemical engineers. The students took all of their courses for the spring semester, senior year, from a single instructor and pooled them into a seamless laboratory project to produce a recombinant protein at pilot plant scale. The students were able to learn how to design experiments, plan and execute runs, and operate a variety of equipment while they learned the biochemistry, molecular biology, microbiology, and theoretical aspects of bioprocessing. The students were tested for knowledge, comprehension, and application level understanding before and after the program and were asked to evaluate their learning experiences as compared to the rest of their undergraduate experience at Penn State. The students were filmed giving presentations of their work and their writing was sampled and evaluated throughout the program. Judging from their responses, the program was highly preferred over traditional classroom work by the students. The instructor saw significant improvement in the knowledge base of the students and their report writing abilities during this program. This paper will present the structure of the program and discuss the lessons learned and potential of similar programs for teaching bioprocessing to engineers.

Introduction

Large universities with large classes can offer a wonderful learning atmosphere for students. Lectures give the listener the opportunity to hear many different ideas and get instruction from people with many different viewpoints and backgrounds. Over the typical 4 or 5 year period at a large university, it would not be unusual for a student to have 2 or 3 classes taught by faculty who are members of the National Academy of Science or National Academy of Engineering. However, for all the educational variety and other advantages, there are several negative aspects to learning at a large university. First, there is often little opportunity for students to do hands-on, tactile learning since most courses are lecture courses. A typical undergraduate in chemical would only be exposed to a laboratory 2 or 3 times during their undergraduate education and some of those labs would be highly structured. Second, since most lecture courses are large, (> 25 students) students don’t normally get to

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“know” the professors well unless the professor and students go out of their way to develop social and professional interactions. And third, because students are shuttled from classroom to classroom and “expert” to “expert”, there is sometimes a lack of technical cohesiveness. Sometimes the instructor focuses on her own area of specialty rather than the big picture. The students may never realize which material is important and which material is merely of interest to a particular professor. Getting similar information from many different sources may leave gaps in the students’ education, or there may be certain unnecessary redundancies in what the students are taught.

Feeling these “flaws” in their education, students often complain that their educational experience has little to do with real life and they sometimes feel that what they are learning is irrelevant to the rest of their career. And because many students become cynical about or act less than interested in their education, the professors can come to feel that the students don’t really know or appreciate the material presented in the courses and are only after grades.

To address some of these perceived problems, we developed and used an educational framework which we called the “Bioprocessing Cluster” for teaching bioprocessing (biochemical engineering) to undergraduate students. At Penn State, chemical engineering students can specialize in areas of concentration called “options” by taking a prescribed set of courses in place of random electives. For example a student can get a “bioprocessing” option by taking an introductory biochemical engineering course, a course in bioseparations, a fermentation laboratory, and a course in advanced reactor design, along with two science courses, one in microbiology and one in biochemistry/molecular biology. The option gives the student exposure to special material not normally taught to the general chemical engineering classes. On the undergraduate degree certificate, the student receives a special designation that they completed the option. The theory is that by completing the option, the student may be more attractive to certain employers choosing between two otherwise equally qualified applicants.

The bioprocessing option is normally accomplished by taking the courses one-by-one over a period of about 2 years. Typically a student will take a microbiology course in the fall of the junior year, a biochemistry course in the spring of the junior year, and then take biochemical engineering and bioseparations the fall of the senior year and reactor design and fermentation lab the spring of the senior year. The final four engineering courses are taught by 3 different instructors.

The bioprocessing cluster, on the other hand, involved taking the four engineering courses as a group, all in one semester, from a single instructor. By setting the program up this way, all of the traditional lecture classroom structure could be eliminated, all of the normal course material could be combined and blended, and the students could do substantial laboratory work on real problems in a real life scenario. The program was conducted in a 9-5 “job” framework, Monday through Friday. The students reported-in in the morning, and left sometime in the late afternoon or early evening on a typical day. What they did during that day depended on the project flow, but all day long they were
giving presentations of the results of the latest experiments or processing runs, learning new techniques, running experiments, reading papers, or writing or reviewing reports. This led to a completely different learning environment and experience for the students. In this paper I will describe the details of the cluster and the results of some measurements of student learning and satisfaction.

Demographics

Over the three year period the cluster was run at Penn State, 10, 9, and finally 16 students were involved in the program in 2000, 2001, and 2002 respectively. The first two years were used to get a feel for the program, most of this analysis and the comments which follow apply to year 3 (2002). In year 3, 16 students were involved, 12 female and 4 male students. The students were selected for the program based on interest, not based on GPA, and academically speaking, their qualifications covered the entire class range. All of them were bioprocessing option students and all had expressed interest in biochemical or biomedical engineering. One student had worked in the bioprocessing pilot plant at PSU prior to taking the cluster, and several had done coops at various places. Aside from these things, and the fact that there were more females than males, the cluster involved a fairly uniform cross section of the chemical engineering class.

Course Load

In order to get the program going, I taught the cluster on an overload basis, while teaching the normal version of the bioseparations to a different group of students, but clustering courses for a group of less than 20 students does not necessarily mean that one is underloading or overloading. In terms of the faculty course load (at least for bookkeeping purposes), simple math says that teaching a “cluster” of 5 courses with a relatively small number of students (16 here) is about the equivalent of teaching a single course with 80 students (5 x 16) - typical of a large university. The time commitment on the part of the instructor may be significantly more (see below), but the point of a cluster is to promote more (not less) faculty-student interaction.

Student Teams

Before the first meeting, the 16 students in the cluster were divided into two teams of 8 studente each that worked independently of each other on the same problem in parallel. The student teams were chosen by the instructor to insure that they were evenly balanced in terms of academic abilities (GPA to date) and gender, and with a slight amount of social engineering to avoid personality conflicts as far as possible. Each team was further divided into two groups of 4, one designated as the upstream group and one designated as the downstream group. The groups of 4 were divided into student partners (pairs) that worked on different parts of the project. A student manager was chosen from each group (upstream or downstream) to oversee group progress.

The overall project goal was explained to each team. The upstream group was given the charge to develop the necessary fermentation processes while the downstream group...
started with preliminary investigations of the purification operations. (Later in the term the two groups were switched so that each student got to work on upstream and downstream aspects of the project.)

**Schedule**

The daily schedule was very flexible and arranged on an as needed basis, but usually each team would meet with the instructor twice a week at 9 am with the other team absent. The “Blue” team typically met on Monday and Wednesday and the “White” team met on Tuesday and Thursday. Sometimes both teams would come to the same meeting. These meetings lasted for about 2 hours, sometimes more, sometimes less. The students were given an opportunity to ask questions or bring up a problem or topic, but failing that, the instructor usually initiated a discussion - often by asking a specific pair, group, or the whole team to explain something relevant to the project or to analyze a related work from the literature. These assignments were done “cold” i.e. without seeing them beforehand and with no preparation. Sometimes, as requested by the students, the instructor would give a lecture on a particular aspect of the science, techniques, engineering, or management of the project. On average the students spend about 5 hours per week in this learning environment.

**Instructor Time Commitment**

Substantial instructor time was spent meeting with groups or pairs to discuss planning, progress, or technical issues relating to a particular experiment they were planning, were doing, or had done. This was done in the instructor’s office and away from the other students in the lab. Report critique was reserved for this time and was often quite detailed. On average the students spent about 5 hours per week in this environment (which means the instructor spent about 20 hours per week in this activity.)

The rest of the week, (~30 hours) the students were “on their own” in the lab -- running experiments and tests or having their own meetings. The instructor spent about 10 hours per week with them down in the lab demonstrating or showing them how to run equipment, handle chemicals, or pointing out mechanical issues that they needed to be aware of. Sometimes this was done with a student pair, sometimes with a group, and sometimes with the whole team. The managers were expected to schedule these demonstrations.

Thirty (30) hours is a large amount of instructor time (especially when one is teaching two regular courses and working with two graduate students), but there was a minimum of lecture preparation and grading homework papers for the cluster. For the instructor the set-up was also much more like a job, with take-home work once in a while but not as a matter of plan or routine.
Project Description

The project was chosen to maximize the number of key “bioprocessing” issues addressed, independent of the courses for which the students would be given grades. The assignment was given the first day as “to produce 1 to 10 grams of active bovine chymosin using the E. coli cells with the plasmid provided”. They were given a draft of a master’s thesis (Shanter, 2002) concerning the refolding kinetics of prochymosin, and a paper on similar topic in which the researchers had genetically engineered porcine pepsin DNA into an E. coli cell and expressed the enzyme.

Though not explicitly discussed with them, in order to accomplish their goal the students would need to learn how to do a number of steps in the production process. The steps and some detail on what each step would require in terms of student learning are shown in Table 1.
Table 1. Processing steps required for the Cluster project

<table>
<thead>
<tr>
<th>Process Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fermentation</td>
<td>Learn how to make and design media. Learn how to inoculate and grow cells in shake flasks. Learn how to plate. Learn how to assemble and operate a 5 L reactor. Learn how to measure cell growth and glucose utilization. Learn how to assemble and operate a 150 L reactor. Learn how to design the fermentation process to maintain pH, allow for fed batch operation, maintain DO and cause protein induction.</td>
</tr>
<tr>
<td>Cell recovery</td>
<td>Learn how to operate a benchtop centrifuge. Learn how to operate a floor model centrifuge. Learn how to operate continuous (pilot scale) centrifuge. Learn how to estimate rotation speeds and scale-up from small to pilot scale.</td>
</tr>
<tr>
<td>Cell lysis</td>
<td>Learn how to operate a sonicator. Learn how to operate a pilot scale homogenizer. Learn how to measure cell lysis. Learn how to design a lysis operation to maintain temperature limits.</td>
</tr>
<tr>
<td>Inclusion body recovery</td>
<td>Learn how to do differential centrifugation. Learn how to scale-up a centrifugation operation. Learn how to run SDS electrophoresis gels. Learn how to do interpretive and quantitative gel analysis.</td>
</tr>
<tr>
<td>Solubilization</td>
<td>Learn how to design solubilization and unfolding solutions. Learn how to design buffers. Learn how to model batch reaction kinetics.</td>
</tr>
<tr>
<td>Refolding</td>
<td>Learn how to design a refolding reactor. Learn how to design refolding processes. Learn how to do biological/enzyme assays.</td>
</tr>
<tr>
<td>UF/DF concentration</td>
<td>Learn how to operate Amicon cells. Learn how to operate a small scale UF/DF device. Learn how to design a UF/DF process. Learn how to operate a pilot scale UF/DF device.</td>
</tr>
<tr>
<td>Chromatography</td>
<td>Learn about different resins. Learn about protein-resin interactions. Learn how to conduct capacity and binding estimations. Learn how to operate an HPLC. Learn how to design gradient separations. Learn how to do quantitative HPLC assay. Learn how to design a large (20 L) chromatography column process (scale-up).</td>
</tr>
</tbody>
</table>
Assessment

The cluster program was assessed in four main ways as shown in Table 2.

Progress

The students were given clear instructions to try to accomplish the 1 -10 gram goal. (This goal would just have been barely possible by a group of 2 or 3 well trained professional engineers working full time with the resources available.)

Exams

The students were tested using conventional question and answer exams at the end of the term to give a numerical assessment of their knowledge, understanding, and analytical capabilities regarding the science, techniques, and engineering (calculational) aspects of bioprocessing. In the case of their science knowledge, tests were also given before the cluster so that any improvement could be quantified. Engineering tests given before the cluster revealed only that the students had a modest qualitative understanding of bioprocesses, but minimal quantitative understanding of them. The results of the pre-engineering tests were otherwise difficult to compare to the end of term exam results.

Table 2. Cluster Assessment

<table>
<thead>
<tr>
<th>Assessment Method</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Progress</td>
<td>Determined by how far the students got toward achieving the stated goal of 1 -10 grams of active chymosin.</td>
</tr>
<tr>
<td>Exams</td>
<td>Determined from students’ ability to correctly answer questions regarding science, technique, and engineering typical of well trained biochemical engineers.</td>
</tr>
<tr>
<td>Reports</td>
<td>Determined from the quality of thought of students formulating written and oral plans, instructions, and reports on the experiments they studied.</td>
</tr>
<tr>
<td>Student satisfaction</td>
<td>Determined from questionnaire feedback on student perception of the value of this education</td>
</tr>
</tbody>
</table>

Reports

The students regularly were asked to give oral and written reports and updates to their team and to the instructor. The quality of these reports was assessed to give an snapshot of the report writing capabilities of the students.
Student Satisfaction Survey

A 13 question student survey was given at the end of the term to determine the level of student satisfaction with the cluster experience and (especially) to compare it to their previous student experiences with engineering education at Penn State.

Results

Progress toward project goal

Neither student team accomplished the final goal of producing 1 -10 grams of refolded and active bovine chymosin, however both teams made substantial progress (see Table 3).

The teams worked at three different scales, usually first testing a process at a small scale using shake flask cultures or the equivalent amount of commercial protein one would expect to get from a 50 cc culture. Success at 50 cc scale was followed by process development at a scale equivalent to the production one would get from a 5 L culture. Success at 5 L was followed by tests and process development at the 150 L scale. In the table, having a viable process at the larger scale means that there were also viable processes at the smaller scales. Refolding was a particularly difficult process (true in the real world too) and seemed to be the bottleneck for process development for both teams.

Table 3. Student progress toward project goal

<table>
<thead>
<tr>
<th>Process Step</th>
<th>Blue Team Progress</th>
<th>White Team Progress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fermentation</td>
<td>Viable Process @ 150 L</td>
<td>Viable Process @ 150 L</td>
</tr>
<tr>
<td>Cell recovery</td>
<td>Viable Process @ 150 L</td>
<td>Viable Process @ 150 L</td>
</tr>
<tr>
<td>Cell lysis</td>
<td>Viable Process @ 150 L</td>
<td>Viable Process @ 150 L</td>
</tr>
<tr>
<td>Inclusion body recovery</td>
<td>Viable Process @ 5 L</td>
<td>Viable Process @ 5 L</td>
</tr>
<tr>
<td>Solubilization</td>
<td>Viable Process @ 5 L</td>
<td>Viable Process @ 5 L</td>
</tr>
<tr>
<td>Refolding</td>
<td>Viable Process @ 5 L</td>
<td>Unproven Process @ 50 cc</td>
</tr>
<tr>
<td>UF/DF concentration</td>
<td>Unproven Process @ 50 cc</td>
<td>Viable Process @ 5 L</td>
</tr>
<tr>
<td>Chromatography</td>
<td>Unproven Process @ 50 cc</td>
<td>Viable Process @ 50 cc</td>
</tr>
<tr>
<td>Design Program</td>
<td>90 % Complete</td>
<td>60 % Complete</td>
</tr>
</tbody>
</table>

although the Blue team did appear to have a viable process at the end. The teams were also asked to learn how to use “SuperPro” Designer software near the end of the course and to model a protein production/refolding process on the software. Neither group finished the design but both groups made substantial progress.
Exams

Table 4 summarizes the exam results from conventional testing done at the end of the term. The students were tested on science and techniques (separate tests) by having them give oral answers to 10 questions selected randomly from a group of 50 questions relevant to bioprocessing. The engineering test was a scored, quantitative take-home test very similar to a normal (and highly challenging) test one might get in an engineering course.

Table 4. End of term exam results

<table>
<thead>
<tr>
<th>Test Coverage</th>
<th>Class average</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science</td>
<td>70.1</td>
<td>41.5 – 96.5</td>
</tr>
<tr>
<td>Techniques</td>
<td>75.1</td>
<td>49.0 – 92.0</td>
</tr>
<tr>
<td>Engineering calculations</td>
<td>79.8</td>
<td>57.0 – 92.6</td>
</tr>
</tbody>
</table>

The science exam results were compared to a similar (but written) exam given at the beginning (pre-cluster) of the term covering material covered in the microbiology and/or biochemistry/molecular biology courses the students had taken the previous year. Figure 1 shows a comparison of the scores achieved pre and post cluster for each student ranked according to the score the student achieved on the pre test. The average score improved from about 36 to 70 pre and post cluster. (Though I personally don’t think so, one can argue that the improvement in scores is at least partially due to the form of the test. It would be harder to argue that the relative improvement of students that scored poorly on the pre test is due to this fact.)

All of the students scored better on science questions after they had taken the cluster. The improvement was more substantial in many of the students that had low scores coming into the cluster. Neither set of scores correlated to the student GPA or grades in their science courses (data not shown).

Reports

The students were assessed for their “management” abilities by numerically rating the overall quality of their reports, formal and informal run documents, planning documents, and oral reports and discussions. The average scores (on a basis of 10 maximum) are shown in Table 5.
For the most part, the reports were more than satisfactory, and a few of the lab reports from later in the course would be considered “impressive” considering they were written by undergraduate students. Planning and run documents were less impressive perhaps, but clearly having to plan their own experiments and process runs was new to the group. There was also an improvement in the quality of these types of documents as the course progressed (data not shown).

Table 5. Management (Report) Scores

<table>
<thead>
<tr>
<th>Document Type</th>
<th>Average</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning</td>
<td>8.06</td>
<td>7 - 9</td>
</tr>
<tr>
<td>Run Document</td>
<td>7.25</td>
<td>7 - 9</td>
</tr>
<tr>
<td>Report</td>
<td>8.81</td>
<td>8 - 10</td>
</tr>
<tr>
<td>Oral Reports</td>
<td>8.19</td>
<td>7 - 9</td>
</tr>
</tbody>
</table>
Student Assessment

Table 6 shows the results of a “student assessment” of the course done at the end of the term. Eleven “scaled” questions (1 = less/worse/lost to 7 = more/better/gained with 4 = about the same were posed to the students. Two open ended questions on what they would change the cluster if given the chance and how they would approach the cluster differently in hindsight were also asked.

Question 12 asked what the students would do to change the cluster given the chance. Three fourths (12/15) mentioned that they would either modify or eliminate the student managerial position on the grounds that the managers were difficult to get along with (in a personal way) and ineffective and having someone in charge who knew little more than everyone else was annoying. Two thirds (10/15) made a specific reference to the instructor participating more by either offering (more) unsolicited lectures, or by giving more direct guidance and supervision. The students clearly preferred to be led by the instructor, not a fellow student.

Question 13 asked how they personally would approach the cluster differently next time given the chance. The answers were not as uniform as in 12, but they centered around the need get going sooner or ask more questions (read more) and be more willing to express their opinion and take a stand on issues. The students as a whole recognized the need for them to be more active in the learning process.

Considering the general satisfaction with the cluster as a whole, the score for Question 3 seemed out of line with the rest of questions, so the students were asked to comment on their feeling that they or their partners had not gained confidence as much as they had learned some of the specific skills. The answer was that the cluster experience had shown them how little they knew about real engineering coming into the cluster and how much of the classroom work they had done their first 3 ½ years was not helpful in a “real engineering” situation.
Table 6. Student comparative assessment of the cluster program

<table>
<thead>
<tr>
<th>Question</th>
<th>Average Rating</th>
<th>Rating Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Compared to other semesters, I learned (less or more) about engineering this term.</td>
<td>6.13</td>
<td>5 - 7</td>
</tr>
<tr>
<td>2. Compared to other semesters, I found the learning experience (less or more) enjoyable this term.</td>
<td>6.67</td>
<td>5 - 7</td>
</tr>
<tr>
<td>3. I feel that I (lost or gained) confidence in my engineering ability this term.</td>
<td>5.67</td>
<td>4 - 7</td>
</tr>
<tr>
<td>4. Compared to other semesters, I learned (less or more) “useful” things this term</td>
<td>6.80</td>
<td>6 - 7</td>
</tr>
<tr>
<td>5. Compared to other semesters, I learned how to plan (better or worse)</td>
<td>6.60</td>
<td>6 - 7</td>
</tr>
<tr>
<td>6. Compared to other semesters, I learned how to work in a group (better or worse)</td>
<td>6.40</td>
<td>5 - 7</td>
</tr>
<tr>
<td>7. Compared to the start of the semester, I feel that professional communication is (less or more) important now</td>
<td>6.73</td>
<td>5 - 7</td>
</tr>
<tr>
<td>8. Compared to the start of the semester, I feel (less or more) confident in my ability to work with equipment</td>
<td>6.80</td>
<td>4 - 7</td>
</tr>
<tr>
<td>9. Compared with the start of the semester, I feel (less or more) confident in my ability to plan technical activities</td>
<td>6.50</td>
<td>6 - 7</td>
</tr>
<tr>
<td>10. Compared to the start of the semester, I feel (less or more) confident in my ability to read and understand scientific papers relating to bioprocessing</td>
<td>6.47</td>
<td>5 - 7</td>
</tr>
<tr>
<td>11. Compared to the start of the semester, I feel (less or more) confident in my ability to design bioprocesses</td>
<td>6.47</td>
<td>6 - 7</td>
</tr>
</tbody>
</table>

Discussion

As compared to traditional education (i.e. mainly based on lectures) as currently practiced at most large schools, there are both positive and negative aspects of the cluster approach.

First I will present the negative aspects. I have taught biochemical engineering, bioseparations, and fermentation lab (as well as a number of different standard chemical engineering courses) many times in the traditional (lecture) format or in a unit-by-unit laboratory structure. Doing the same material in the cluster format gives one the feeling that you are not covering the same volume of material. Instead of “covering” several growth models for cells, the cluster approach allows the students to explore only one or...
two. Design tends to become focused on scheduling and sequencing issues, not theoretical considerations of the design process or use of design software. Overall students learn to find “a” way and not to hear about “all the ways” of accomplishing something. I am convinced that the students’ comments that there was “not enough lecture” reflected the lack of what I call the “feeling of efficiency” in learning that good lecturing gives the listener. There is no doubt that one can “cover more ground” by lecturing.

Having done the cluster, I would agree that lecturing remains the fastest way to convey information, but I would not agree that it is the “most efficient” if learning is the goal. If one wants students who can discuss technical issues and solve technical problems at the end of the educational experience, the cluster seems to be more efficient at producing this result. The cluster proved that even without formal lectures students can understand complex technical material (like bioprocessing) and can “accomplish much”. The cluster students went a long way toward accomplishing the ambitious task of producing a refolded, active protein from a recombinant DNA containing laboratory cell. They learned the science behind their process (and more), learned bioprocessing techniques, and were able to do both the practical and mathematical design associated with bioprocessing. By the end of the term, not only were the students knowledgeable about the equipment and processes normally discussed in a class, but they had experienced them first hand. They had also seen the reality of making plans, seeing things fail and succeed, and experienced the difficulty of getting and reporting intelligible results.

Despite the dearth of lecture they were exposed to, they were even able to perform well on conventional tests and appeared to have added to their knowledge of science facts, even those not explicitly taught in the cluster. Doing biotechnology (versus hearing about it) enhanced their basic science knowledge base. In addition, there appeared to be an equalizing effect among the group. Students that scored the lowest on science knowledge coming into the cluster, tended to gain the most knowledge, making them almost as knowledgeable as the initially high achievers by the end of the cluster. This might be due to more closely addressing their preferred learning styles, or simply because they felt they had more of a chance to compete with higher achievers in this “level playing field” where getting things done was valued more than test taking skills.

The students also improved their communication skills. They learned how to plan activities, coordinate schedules, and prepare run documents, all of which require thinking ahead. They learned how to think on their feet, make quick evaluations, and present things orally to others. They got practice in report writing and critical input to their communication skills.

Students appeared to appreciate the cluster. Not only did they give it high ratings at the end of the term, but more than half of the students have written to me in the year and a half since the cluster was given to specifically thank me for the experience and/or to tell me how valuable it was for them in their job search. The two most common comments are that the cluster experience: 1) gave them confidence in the interview and 2) gave them a fast start at their new job. Their experience is that they had an “advantage” over
other applicants because they had used, not just learned about, all the equipment at their new company and had done, not just heard about, the techniques one actually uses to solve a bioprocessing problem. Apparently no one thought it important that they “solve a differential equation” before hiring them, but many employers valued the many skills they had.

As an educator, I see things a little differently from the students even in the success of the cluster. To me the success in a “cluster” approach includes but goes beyond the success in them finding a good job in their chosen field. To me, though success in higher education is hard to measure, there are two goals that are worth driving toward. The first goal is a more or less impersonal simple acquisition of knowledge. We want our students to “know more” facts, have better skills in problem solving, to have come into contact with more ideas, and to be deeper thinkers. Progress toward this goal is traditionally achieved through lectures and labs or through discussions with the professor in the office using conventional education methods. We measure the success of reaching this goal by homework scores, test scores, and report scores. The results here indicate that even using the same measuring tools as conventional education, by all accounts, the cluster approach works in terms of this goal. The students do “learn the material” -- and more.

The second goal is personal and not usually addressed in conventional education, at least not at the large research university. We want our students to enjoy and benefit from the experience of a college education. We want this 4 years to be not only profitable, but pleasant, something that they will remember and look back on with fondness. We want the students to have a favorite professor, favorite class, and memorable experience. The cluster approach has provided me and my students with a memory. During the cluster experience I got to know the students and they got to know me. How can one improve upon that as an educational experience? The cluster experience shows that large schools do not have to be impersonal places, and all the personal experiences of higher education do not have to occur outside the classroom.

Dr. Larry Spence, former Director for the Center for Innovative Teaching at Penn State wrote a thought provoking article recently called “The Case against Teaching”¹. He addressed three premises about teaching that I think are apropos to the cluster program. First, he states that the singularly best teaching method is one-on-one and that the larger the class, the worse the instruction gets. Teaching is not about great lectures, but about communication between two human beings. That has never changed and will never change. No amount of teacher enthusiasm for the subject matter can improve the learning experience. My experience with the cluster is that though students feel they learn from lecture, they actually (and best) learn through one-on-one discussions with the instructor and/or each other. To some, this kind of learning is slow and repetitive, but it is also effective!

Dr. Spence’s second premise is that human beings are “fantastic” learners – with almost limitless capability to learn. However “fantastic” learning is not the result of a large brain with a high capacity for facts, but a brain that “represents rather than records reality”. Our brain works by doing things and adjusting to the results. “Cluster” learning allows feedback and adjustment between the teacher and student similar to the way that

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experiencing things daily in life allows feedback and adjustment. The best way for us to learn is to do (and sometimes to fail) - the next best thing is for us to discuss things one-on-one with someone else. The cluster approach allows this opportunity.

Dr. Spence’s third premise is that “teaching focused” classrooms don’t work for learning. The best that can happen in a teaching focused atmosphere is a temporary ability to recall the material. Even a few weeks later, students forget what they have learned. He goes on to imply that successful students are actually ones that find ways to go around the basic teaching focused classrooms, by finding ways to interact with the professor one-on-one outside the classroom and to do things “on their own” like additional self assignments. The cluster program makes this way of learning “part of the plan.”

After experiencing the cluster, no one can convince me (or I doubt any of the participating students) that a program like this does not work better than lectures for student learning. The cluster approach adds the indispensable element of hands-on learning to the curriculum.

Bibliography


Biographical Information

Dr. Alfred Carlson is a Professor of Chemical Engineering at the Rose-Hulman Institute of Technology. Prior to joining Rose-Hulman in 2002, Dr. Carlson taught at Penn State University for 19 years.