# Improving the Chemical Engineering Curriculum through Assessment: Student, Faculty, Staff, Alumni, and Industry Input

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## Introduction

In response to requirements set forth by ABET2000 for the accreditation of engineering programs, the Deptartment of Chemical Engineering at MTU has been assessing its curriculum since 1995 (as described in a prior conference proceedings[1]) using a series of assessment tools developed over the succeeding six years. Three of the tools, the department skills test and the senior exit surveys and interviews, were implemented for the first time in 1999. This paper will discuss the results of our assessments, focusing on 1999-2001, and how the department is using those results to improve instruction.

The eight tools of the MTU Chemical Engineering Assessment Program are the following: skills test, analysis of design reports, senior exit interview, alumni survey, writing portfolio, oral presentation skills, safety program, and performance on fundamentals of engineering exam.

## Tool #1–Skills Test

Tool #1 in the department's assessment plan is "department designed skills test to be given to the students in the Spring Quarter in the Unit Operations Laboratory. The test will measure fundamental knowledge, design skills, and problem solving skills." The metric is "60% pass rate (>70 out of 100 score)."

A multiple-choice test with 22 questions was given late in the Spring Quarter, 2001 to eighty-three graduating seniors. This test was different than the previous year, when the test was composed of 13 questions. The students were bribed to take the exam by offering free pizza. However, many took it seriously when told it helped with accreditation. The questions covered the following areas: Fundamentals (basic definitions, unit conversions, mass balances, and energy balances); Transport Phenomena (fluid flow, heat transfer, and mass transfer); Thermodynamics; and Kinetics/Reactor Design. The overall results of the test are summarized in Table 1 below.

60% of the students answered 13/22 questions or better for a score of 59% or better on the exam. Only 19% of the students answered the required 16/22 or better to achieve at least a 70% score (considered passing by this metric). It is proposed to use the same exam next year to try and get an accurate measure of where our students are and to decide on an appropriate metric. We could also collaborate with another school to compare test results.

**Table 1. Skills Test Results**

| | 2000 | 2001 |
|---|---|---|
| Fundamentals | 65% | 69% |
| Transport | 63% | 48% |
| Reactor Design | 46% | 28% |
| Thermodynamics | 40% | 35% |

Tool #2—Analysis of Design Reports

Tool #2 of the department's assessment plan is "plant design reports and the AIChE senior design project. Faculty not involved in teaching plant design will review these for fundamental knowledge, innovation, research, and problem-solving skills." The metric is a "95% pass rate (>70 out of 100 score)."

This assessment builds on the previous data acquired in the last three years. This data includes critiques of design reports by UOP as a part of the 1998 Davis W. Hubbard Award competition, industrial critiques of student oral presentations in the plant design class made by industrial friends in 1999, and recommendations based on a visit to Pennsylvania State University by Professor Daniel Crowl of MTU in 1999.

Recently, sixteen written reports from spring 2001 were critiqued by faculty members. Industrial input was solicited from student presentations in the spring 2001 plant design course. The reports were ranked in four categories: writing style, technical accuracy, safety and environmental considerations, and appropriate conclusions from data presented. Some general conclusions are summarized in Table 2 below, with more detailed comments in Appendix 1 at the end of this paper.

Tool #3—Senior Exit Interview

Tool #3 of the department's assessment plan is "exit survey and exit interview of graduating seniors. The department chair will administer these in the Spring Quarter to ascertain fundamental knowledge, critical-thinking skills, and overall experience." The metric is "3.0 on a scale of 1-4 on rated questions."

This report summarizes the results of the exit surveys. The 2001 exit surveys were completed by eighty-six graduating seniors. The rated questions requested responses of Excellent (4), Good (3), Fair (2), or Poor (1). The 1999 and 2000 exit surveys were completed by forty-seven, and eighty-two graduating seniors, respectively. The results of these surveys are summarized in Tables 3 and 4.

**Table 2. 2001 Design Reports Analysis**

- Overall
  - Technical content: 79% (27.6/35 possible)
  - Presentation: 83% (28.9/35 possible)

- Technical / Economic Aspects

Strengths
Good observations regarding catalyst
Equations nicely presented

Weaknesses
Percent recovery high (3)
Strategy *not* a strategy but a recipe
Indicate set point and steam change on the graph of composition
Look at meters to resolve ethanol balance
But gallons are not mass!

- Presentation Aspects

Strengths
Balanced / well done out presentation (3)
Not a bad presentation

Weaknesses
Poorly dressed (4)
Graphs difficult to read (2)
Equations difficult to read (2)

**Table 3. Senior Exit Survey: Preparation In Chemical Engineering Fundamentals**

| | **1999** | **2000** | **2001** |
|---|---|---|---|
| **Mass and Energy Balances** | **3.6** | **3.6** | **3.5** |
| **Separation Processes** | **3.1** | **3.0** | **2.9** |
| **Unit Operations** | **3.1** | **3.2** | **3.4** |
| **Transport Phenomena** | **2.4** | **2.7** | **2.8** |
| **Systems Engineering and Controls** | **3.0** | **2.8** | **2.8** |
| **Thermodynamics** | **2.9** | **1.8** | **2.0** |
| **Kinetics and Reactor Design** | **3.3** | **2.7** | **3.1** |

**Table 4. Senior Exit Survey: Integration Of Concepts Throughout The Curriculum**

| | 1999 | 2000 | 2001 |
|---|---|---|---|
| **Environmental Issues** | **2.2** | **2.0** | **2.5** |
| **Process Safety** | **3.2** | **3.2** | **3.4** |
| **Problem Definition** | **3.0** | **2.9** | **3.0** |
| **Equipment Design** | **2.6** | **2.8** | **2.5** |
| **Technical Writing** | **3.4** | **3.6** | **3.3** |
| **Technical Presentations** | **3.5** | **3.5** | **3.5** |
| **Experimental Design** | **2.7** | **2.7** | **2.7** |
| **Process Design and Analysis** | **3.1** | **3.0** | **2.8** |

Non-technical engineering skills such as decision making, ethics, teamwork, societal impact awareness, project management, public interaction, global awareness, diversity, entrepreneurism, and continuous learning were also tested. In addition, twenty students were interviewed by the department chair. Department strengths include: professors/instructors (reported by 11 students), unit operations laboratory (4), size of department/classes (4), teamwork (2), hands-on experience (2), encouragement/motivation (2), and faculty-student closeness (2). Areas needing improvement included student advising (5), computers (5), and professors/instructors (4).

Students also found career advising from the university career center to be generally positive. Additional comments included: the need to increase the number of credits and reduce the amount of group work during the senior plant design courses.

Tool #4—Alumni Survey

Tool #4 of the department's assessment plan is "survey of alumni two and five years out. These will be conducted by the College of Engineering and by the department. The assessment committee will evaluate the results for fundamental knowledge, communication skills, professional ethics, contemporary/global issues, and environmental/safety issues." The metric is "3.0 on a scale of 1-4 on rated questions."

This report summarizes the results of the 2001 alumni surveys. The survey form (copy attached) were completed by eleven (11) members of the class of 1995 and seventeen (17) members of the class of 1998. Pursuant to the above statement of Tool #4, the results are summarized below in Table 5:

**Table 5. 2001 Alumni Survey of ABET Outcomes***

| ABET Goal | Description | Class of 1995 | Class of 1998 |
|---|---|---|---|
| (a) | apply knowledge of mathematics (aM),<br>science (aS) including computer science (aCS),<br>and engineering (aE) | 3.1 (aM)<br>3.0 (aS)<br>2.7* (aCS)*<br>3.4 (aE) | 2.5 (aM)<br>3.0 (aS)<br>2.7 (aCS)*<br>3.5 (aE) |
| (b) | design and conduct experiments (bE), as well as to analyze and interpret data (bD) | 3.6 (bE)<br>3.9 (bD) | 3.3 (bE)<br>3.7 (bD) |
| (c) | design a system, component, or process | 3.4 | 3.1 |
| (d) | function on multi-disciplinary teams | 3.8 | 3.7 |
| (e) | identify, formulate, and solve engineering problems | 3.6 | 3.8 |
| (f) | understand professional and ethical responsibility | 3.6 | 3.3 |
| (g) | communicate effectively-oral (gO) & written (gW) | 3.5 (gO)<br>3.6 (gW) | 3.6 (gO)<br>3.5 (gW) |
| (h) | impact of engineering in a global and societal context | 2.8* | 2.7* |
| (i) | need for, and an ability to engage in, life-long learning | 3.1 | 3.0 |
| (j) | knowledge of contemporary issues | 2.2* | 2.5* |
| (k) | use the techniques, skills, and modern engineering tools necessary for engineering practice | 3.3 | 3.4 |

* Possible problem area

In addition to measuring the above criteria, alumni were queries with regard to: apply knowledge of humanities, apply knowledge of social sciences, apply knowledge of business/finance, ability to function in culturally/ethnically diverse environments, ability to use computing technology in communications, ability to use computing technology in engineering analysis/design, ability to synthesize and integrate knowledge across disciplines, ability to use a wide range of experimental apparatus, environmental aspects of engineering practice, practice of engineering on a global scale, relation of engineering to societal and cultural issues, and preparation to become a licensed professional engineer.

In addition to responding to the above questions that were asked of all alumni from the college of engineering, alumni were polled with several departmental specific questions. The most liked aspects of the curriculum were: faculty helpful and available, program challenging and intense, hands on experience, labs, and a real world emphasis. The least liked aspects of the curriculum were: long formal reports, not enough business education, too much theory, lack of real-life applications, professors not specific in objectives, no career advice, lack of theory, and a lack of flexibility in course scheduling. The courses students found to be most useful included: plant design, unit operations laboratory, and technical communications. The courses students found to be the least useful were kinetics, process control, physical chemistry, and FORTRAN programming.

Students felt well prepared for industrial safety practices (39.5/41 yes votes) with the preparation stemming equally from the required safety and unit operations courses. Students also felt well prepared to prepare written reports and give oral presentations (41/41 votes) with the preparation being from experience in the technical communications, unit operations, and plant design courses.

When asked how the curriculum could be modified, students asked for additional courses in the statistical design of experiments, communication skills, economics, and process equipment. They also asked for help with career planning and help in finding internships.

Tool #5—Analysis of Written Materials

Tool #5 of the department's assessment plan is "Portfolio of written materials in capstone and communication courses. Faculty and an industrial group will evaluate for communication and teamwork skills." The metric is "85% pass rate (>80 out of 100 score)."

Like Tool #2, this tool still needs to be fully implemented. The only data on hand at this point are critiques of design reports by UOP as a part of the 1998 Davis W. Hubbard Award competition.

Four (4) reports pre-selected by the MTU Chemical Engineering Plant Design Faculty were critiqued in 1998 by three MTU alumni at UOP. A summary of the comments on writing is presented below in Table 6.

**Table 6. Summary of 1998 UOP Analysis of Design Reports**

- Strengths
  Organization and style are acceptable (4)
  Well formatted (2)
  Well written (1)
  Conclusions are given in the cover memo (3)
  The IRR and NPV are given in the cover memo (1)

- Weaknesses
  Overall the reports are not as good as the previous year
  Did not quote the IRR or NPV in the cover memo (2)
  Do not use "cute" titles (2)
  No conclusions and recommendations in the cover memo (1)
  Poor text formatting (1)
  Unconventional symbols used (1)

Tool #6-Summary of Analysis of Oral Presentations

Tool #6 of the department's assessment plan is "Portfolio of oral presentations in capstone and communication courses. Faculty and an industrial group will evaluate for communication and teamwork skills." The metric is "80% pass rate (>70 out of 100 score)."

Like Tool #2 and Tool #5, this tool still needs to be fully implemented.

The department of Chemical Engineering is currently collecting data based on student performance in the 2000-2001 academic year, funded in part by a grant from the Center for Teaching, Learning, and Faculty Development at MTU to Jason Keith and Tony Rogers. This grant allowed Jason Keith to travel to visit two companies (Lafarge Corporation, Alpena, MI; BASF Corporation, Mount Olive, NJ) in an attempt to solicit feedback. The data is summarized below.

Professor Jason Keith videotaped six oral presentations by MTU students in the Plant Operations Lab in spring 2001. Copies of the videotapes are available in the department office. Three of the presentations were sent to industrial contacts for feedback. Some of the comments stated that the presentation skills place students in lower third in comparison with other universities, the visual aids were too small to read, the purpose is unclear as to how visual aids fit in with selling the project, the students were very soft-spoken and gave impression of lack of faith in their work, the students were dressed inappropriately for major presentation, and groups did not appear to function as teams.

Professor Daniel Crowl (MTU) visited the chemical engineering department at Pennsylvania State University in May, 1999 to observe the oral presentations by their students. His recommendations are to consider using poster sessions, consider requiring a detailed thermodynamic/physical property analysis, consider requiring a more detailed flowsheet, consider requiring more detailed analysis on one major process unit (could include HAZOP, controller design, simulation, etc.), consider more active involvement of industry with the project, report, and oral presentations, and consider requiring more process detail.

Tool #7—Unit Operations Laboratory "PAWS" Program

Tool #7 in the department's assessment plan is "student participation in the 'PAWS' Safety Program in the Unit Operations Laboratory. A faculty committee will evaluate the level of participation to assess professional responsibility and safety awareness." The metric is "continued improvement; > 70% of 'PAWS' forms to be generated by students not in the Safety Committee." Results from the PAWS program is illustrated in table 7 below.

## Table 7. Summary of "PAWS" Forms (1993-2001)

| | 1993-1994 | 1994-1995 | 1995-1996 | 1996-1997 | 1997-1998 | 1998-1999 | 1999-2000 | 2000-2001 |
|---|---|---|---|---|---|---|---|---|
| Number of Experiments | 7 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Number of Students | 89 | 100 | 113 | 93 | 98 | 94 | 109 | 96 |
| UNSAFE ACTS | | | | | | | | |
| **Spills** | **34** | **8** | **2** | **3** | **10** | **9** | **8** | **2** |
| Dealing With Chemicals | | | | | | | | |
| Chemical Labeling | 13 | 11 | 5 | 4 | 8 | 5 | 5 | 4 |
| Chemical Storage | 5 | 3 | 2 | 10 | 3 | 1 | 2 | 3 |
| Chemical Handling | 7 | 12 | 5 | 4 | 8 | 3 | 5 | 4 |
| No MSDS | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 4 |
| **Chemical Total** | **25** | **28** | **13** | **18** | **19** | **9** | **12** | **15** |
| Housekeeping | 24 | 7 | 8 | 9 | 6 | 9 | 8 | 7 |
| Personal Protective Gear | | | | | | | | |
| Eyewear | 7 | 27 | 16 | 5 | 6 | 5 | 18 | 3 |
| Footwear | 4 | 10 | 3 | 4 | 4 | 1 | 3 | 1 |
| Hardhat | 0 | 8 | 6 | 6 | 2 | 7 | 10 | 2 |
| Gloves* | 0 | 0 | 0 | 4 | 2 | 4 | 7 | 4 |
| Earplugs* | 0 | 0 | 0 | 1 | 0 | 1 | 4 | 3 |
| Other | 11 | 6 | 15 | 2 | 3 | 4 | 7 | 1 |
| **Protective Gear Total** | **22** | **51** | **40** | **22** | **17** | **22** | **49** | **14** |
| Ladders | 15 | 8 | 2 | 2 | 3 | 3 | 1 | 0 |
| Unattended Equipment | 10 | 7 | 4 | 6 | 6 | 6 | 12 | 1 |
| Handling Glassware | 8 | 6 | 3 | 3 | 3 | 6 | 8 | 5 |
| Lockout | 5 | 2 | 0 | 0 | 1 | 1 | 1 | 1 |
| Misc. Unsafe Acts | 24 | 14 | 8 | 11 | 13 | 10 | 18 | 15 |
| **Total No. of Unsafe Acts** | **167** | **131** | **80** | **74** | **78** | **75** | **117** | **60** |
| EQUIPMENT PROBLEMS | | | | | | | | |
| Leaks | 25 | 11 | 6 | 24 | 19 | 13 | 40 | 15 |
| Safety Equipment | 18 | 1 | 4 | 13 | 17 | 12 | 15 | 11 |
| Electrical | 16 | 5 | 1 | 6 | 3 | 2 | 4 | 7 |
| Faulty Equipment | 15 | 6 | 6 | 9 | 8 | 11 | 9 | 7 |
| Hot Surfaces | 4 | 0 | 0 | 4 | 1 | 9 | 3 | 2 |
| Odors | 4 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| Guards Missing | 3 | 5 | 0 | 1 | 1 | 0 | 1 | 0 |
| Misc. Equipment Problems | 17 | 13 | 16 | 13 | 16 | 16 | 29 | 8 |
| **Total No. of Equip. Problems** | **102** | **41** | **33** | **71** | **66** | **63** | **101** | **50** |
| Safety Suggestions | 0 | 6 | 2 | 17 | 15 | 5 | 0 | 3 |
| **Total Number of "PAWS" Forms** | **269** | **178** | **115** | **162** | **159** | **143** | **218** | **113** |
| **"PAWS" Forms From Safety Comm.** | **164** | **71** | **31** | **45** | **63** | **63** | **87** | **38** |
| **% From Safety Committee** | **61%** | **40%** | **27%** | **28%** | **40%** | **44%** | **40%** | **34%** |

- Included in "Other" for 1993-4, 1994-5, and 1995-6

Tool #8—Fundamentals of Engineering Exam

Tool #8 in the department's assessment plan is "Fundamentals of Engineering Exam. A faculty member who is a Professional Engineer will assess the performance for fundamental knowledge, design skills, and problem solving skills." The metric is "90% pass rate." The results are summarized in Table 8 below.

We note that there were significantly more MTU CM students taking the April, 2001 exam because the department subsidized their taking the exam. These results should be interesting to view to get a better gauge to the quality of the average student.

It is also noted that the passing rate was 76%, well below the set metric of 90%. This is the first year the metric has not been met. In fact, MTU students were above national average until this past year. However, this may be statistical in nature since the number of MTU students taking the exam has dropped steadily over the last few years. It would only have taken another 2.5 students passing the exam to meet the national average, and 3.5 to meet the metric. Despite these facts, MTU students still perform better than other CM majors in the state of Michigan.

**Table 8. Performance of Chemical Engineering Majors on the Fundamentals of Engineering Exam**

| | April, 1996 Exam | | | April, 1997 Exam | | | April, 1998 Exam | | | April, 1999 Exam | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MTU | MI | USA | MTU | MI | USA | MTU | MI | USA | MTU | MI | USA |
| ChE Exam | | | | | | | | | | | | |
| Examinees | --- | --- | --- | 18 | 25 | 870 | 26 | 37 | 754 | 27 | 40 | 798 |
| Passed | --- | --- | --- | 18 | 24 | 774 | 25 | 36 | 699 | 24 | 37 | 679 |
| %-Passed | --- | --- | --- | 100 | 96 | 89 | 96 | 97 | 93 | 89 | 93 | 85 |
| | | | | | | | | | | | | |
| Gen'l Exam | | | | | | | | | | | | |
| Examinees | 53 | 59 | 1324 | 25 | 27 | 456 | 26 | 28 | 341 | 5 | 5 | 231 |
| Passed | 49 | 55 | 1121 | 25 | 27 | 392 | 22 | 24 | 276 | 5 | 5 | 192 |
| %-Passed | 92 | 93 | 85 | 100 | 100 | 86 | 85 | 86 | 81 | 100 | 100 | 83 |
| | | | | | | | | | | | | |
| Total | | | | | | | | | | | | |
| Examinees | 53 | 59 | 1324 | 43 | 52 | 1326 | 52 | 65 | 1095 | 32 | 45 | 1029 |
| Passed | 49 | 55 | 1121 | 43 | 51 | 1166 | 47 | 60 | 975 | 29 | 42 | 871 |
| %-Passed | 92 | 93 | 85 | 100 | 98 | 88 | 90 | 92 | 89 | 91 | 93 | 85 |

| | April, 2000 Exam | | |
|---|---|---|---|
| | MTU | MI | USA |
| ChE Exam | | | |
| Examinees | 8 | 13 | 729 |
| Passed | 7 | 10 | 635 |
| %-Passed | 88 | 77 | 87 |
| | | | |
| Gen'l Exam | | | |
| Examinees | 17 | 18 | 256 |
| Passed | 12 | 12 | 214 |
| %-Passed | 71 | 67 | 84 |
| | | | |
| Total | | | |
| Examinees | 25 | 31 | 985 |
| Passed | 19 | 22 | 849 |
| %-Passed | 76 | 71 | 86 |

Using Assessment Data to Redesign the Chemical Engineering Curriculum

In response to the data collected from the Department of Chemical Engineering Assessment Committee, the following changes were made to the curriculum at the transition from quarters to semesters:

- Student preparation in the core area of thermodynamics was considered to be less than adequate, as evidenced by their *course grades, understanding in subsequent courses, and performance on departmental skills assessment tests* - this prompted the addition of a second thermodynamics course to the curriculum.

In the past, all of this material was supplied over one academic quarters. Under semesters, students now take two semester courses: CM3210 Classical Thermodynamics (which focuses on heat engines, the work required to compress a gas, definitions and applications of fundamental properties such as enthalpy and entropy, etc.) which are items that all engineers should have a working knowledge of, and CM3220 Chemical Engineering Thermodynamics (which focuses on gas/liquid, liquid/liquid, solid/fluid equilibria, predicting the behavior of real gases, etc.) which are items that all chemical engineers should have a working knowledge of above and beyond that discussed in CM3210.

- In response to *faculty observations*, another area that received greater attention in the chemical engineering curriculum was the implementation of a junior laboratory course. Senior students in chemical engineering are required to take the CM4110 Unit Operations Laboratory and CM4120 Chemical Engineering Plant Operations Laboratory courses. The exposure to the laboratory equipment within the chemical engineering department makes our graduates "stand out" to industrial recruiters. Students entering the course lacked the fundamental knowledge required to operate the lab equipment. This weakness is now addressed with the CM4990 Chemical Engineering Lab.

- *Faculty observations and student performance in senior design courses* led to a third focus area that was addressed by the department during the semester conversion: the teaching of the transport / unit operations and reactor design courses in the junior year of the curriculum instead of the senior year. This would allow the students to utilize this knowledge in their senior design courses and not be simultaneously taking these courses. Junior students now take CM3110 Transport / Unit Operations 1, CM3120 Transport / Unit Operations 2, and CM3510 Chemical Reaction Engineering.

- As a result of input received on *student written portfolios and student oral presentations*, a fourth focus area were weaknesses in graduating students communication skills. We have received input from UOP and BASF on the quality of the student writing and oral communication skills in the past. We have focused a greater portion of the senior plant design lab CM4851 and CM4861 as well as the technical communications course CM3410 towards improving students communication skills. We have seen an increase in student performance in the past few years.

For example, student reports now discuss whether or not overall material and energy balance calculations close around the system or unit operation being studied. This was a result of industry input.

- A final focus area does not apply to the chemical engineering curriculum but is in regards to one of the tools by which student performance is evaluated: the *chemical engineering fundamentals skills test*. Based upon prior results, this test has evolved into a truer measure of students' understanding.

The test given in spring of 2000 contained 13 questions in several core areas of chemical engineering. None of the questions were related to the others. This made it difficult for us to assess the level of understanding of students in subject areas – they either got it or they did not. The most recent test, from spring 2001, contained 22 questions focusing on the same core areas. The questions now build in difficulty so it is easy to see where students begin to make errors.

## Conclusions and Recommendations

The assessment program within the Department of Chemical Engineering at Michigan Tech has been collecting data since 1995. The most recent accreditation was during a visit during the 1998-1999 academic year. The program described in this paper will be extremely useful in helping the department seek accreditation in 2005.

Bibliography
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## Appendix 1: Summary of Comments from Industrial Reviewers on Oral Plant Design Presentations (2001)

- <u>Writing Style</u>
  Poor cover letter (3)
  Report format very good
  Poorly formatted and difficult to follow
  Report format acceptable, but more of a number dump than an analysis
  Executive summary basically useless
  No overall material balance or utility summary (2)
  PFD sections not appropriate for summary report
  HYSIS flow sheet hard to follow
  Production schedule needs to be on one sheet and reduced to easy-to-read
  Grammar and spelling errors in different places
  Single page flowsheets included, which is good
  Gantt chart on one page, also good, but hard to read
  Wording not clear in the equipment cost section

Extraneous information
Computer-generated output in Appendix is useless

- <u>Technical Accuracy</u>
Market analysis well done and clearly described
Bizarre ideas—using ceramic membrane reactor to produce ethylene rather than industry standard thermal cracker
Too much reliance on patent literature
Capital cost estimate five times too high
Calculations appear to be generally correct
Students didn't seem to understand what an industrial catalyst looks like and its use
Appears students don't understand the concept of what a spared service is and the pumps are not interchangeable between services
Students assumed a delta P rather than calculating the developed head
Did not include royalties in cash flow analysis
Technical mistake in the column sizing
If inflation is included, a higher MAR needs to be applied
Potentially inaccurate assumptions about equipment and investment cost (2)
Capex for plant appears to be about right
Statement ignores economies of scale—which they should know about

- <u>Safety and Environmental Considerations</u>
Safety aspects were considered, but poorly
Safety and environmental considerations given about three sentences - should have had more discussion on handling and design

- <u>Appropriate Conclusions from Data</u>
Analysis confined to North America—leading to incorrect conclusion
Conclusion correct based on their numbers (doubt about numbers)
Improper recommendation to stay in US market
Groups conclusion would not be acceptable (2)