Abstract – This paper explores student work input into design projects in a capstone design class in chemical engineering. Student time sheets, modeled on industrial engineering accounting practices, were utilized as a data source to investigate several related relationships. They covered three terms stretching from Fall 05 through Winter 06. The data covers 115 students working in 29 design teams on 9 different projects. Patterns of student work input were studied in relationship to distribution of work within teams, variance in work input among different projects, pace of work over the course of a term and relationship between work input and project grades. The paper indicates how this data can be useful in monitoring consistency of course content and in giving insight into the concept that different work patterns can produce the same results. Future work is proposed on using similar data to study specific tasks within student projects in order to increase student learning efficiency.

Index Terms – Capstone Design, Chemical Engineering, Design Projects, Student Work Input

INTRODUCTION

Over the past 5 years, the Capstone Design Course in Chemical Engineering at the University of Michigan has been revised to resemble industrial design practice as closely as practical. [1] As a result, design projects have become less structured and the requirement on deliverables has increased. But as a consequence of some of these changes, students regularly report on course evaluation forms that “the amount of work required was NOT appropriate for the credits received.” Some further complained that the project assignments were not “equal” and some required much more work than others.

These complaints were of concern to faculty. While the changes introduced into the course were felt to be genuine improvements, enhancing the student’s education, there was clearly a need for an objective evaluation of projects and student work input.

The first step toward assuring uniformity in the project assignments was the development of Project Evaluation Procedure. This process is conducted as a pre-assignment review of a proposed design project to assure that it is of a comparable complexity to other projects assigned. The form used to document this process is shown in Figure 1. Problems in the Senior Chemical Engineering design class have been evaluated using this system for the last several years. This system intuitively seemed to assure more uniform complexity among projects. Proposed projects that fell outside the guidelines were modified to meet the requirements. Yet until recently there was no evaluation system in place to permit an objective analysis on the true success of this procedure. Further, even if parity among projects had been achieved, there was no measure except subjective student comment on the level of work input to which the projects had been standardized.

In the Winter term of 2005, student timesheets were introduced to serve as a “key” for estimating total engineering to complete a project. The timesheets are shown in Figure II. Using factors developed in industry, the total team work input at the time of project submission is scaled up to give an estimate of the amount of engineering to be included in the project cost estimate. It soon became apparent that these time sheets would also provide data to not only evaluate differences in project work requirements, but also to examine the working patterns of the student design teams.

Timesheets are used in design courses at a number of other universities. [2,3,4,5]. Kumar reports using them to calculate manpower requirements in a civil engineering design course at Southern Illinois University [6] At Florida Institute of Technology, Larochelle uses timesheets as an intrateam evaluation tool for team member performance. [7] The author utilizes timesheets for both these purposes, but in addition finds them an effective tool in evaluating the course itself.

The Data

Students fill out time sheets and turn them in monthly. The time is accumulated over the life of the project until first submission of the design report. There is a period allowed for revision of the report after first grading but this is not counted toward the project time. With a few exceptions, students work in 4-member teams. Individuals keep their own timesheets as a significant portion of the work is divided and done on an individual basis. Individual work time is accumulated over the life of the project until first submission of the design report. The time data submitted by students has a high degree of reliability. The University of Michigan College of Engineering operates under an Engineering Honor Code. Exams are not proctored and all major student work is signed by the student pledging that they have “neither given nor received” unallowed aid in performing that work. The Code has been in place for since 1915. Violations are rare.
UNIVERSITY OF MICHIGAN
DEPARTMENT OF CHEMICAL ENGINEERING

ChE 487 Project Evaluation

PROBLEM TITLE: ___________________________________ {BLOCK DIAGRAM ATTACHED}

PROBLEMSubmitted BY: ___________________________ Date__________
RATED BY: ___________________________ Date__________

(All instructors rate all problems. Submitter has prime responsibility for data verification)

1) All problems must have basic information on the chemistry and any nonstandard physical processes available in the literature (Note: NOT limited to Internet sources)  Problem Complies: _____YES _____NO

2) The chemical and physical properties of all major components must be available in the literature. The chemical and physical properties of minor or intermediate compounds must be either available or readily estimated from documented properties of analogous compounds
   Problem Complies: _____YES _____NO

3) The process shall not be available as a completely developed solution for conditions identical or similar to the problem conditions specified.
   Problem Complies: _____YES _____NO

4) A process scheme for the problem can be developed in 3-5 stages- not counting raw material and product storage or waste treatment. A process stage is a specific reaction or mass transfer step intended to accomplish a distinct objective. Multiple equipment, sequential operations and/or parallel units may be required to reach the objective of that single stage.
   Problem Complies: _____YES _____NO

5) All problems should contain elements of “self education”. But with the a few exceptions, problems should NOT contain basic engineering concepts to which the students have not been exposed.

The above serves as an over all guideline only. The nature of the problems and the students’ unique approaches to their solution will make some projects inherently more difficult than others. That is a reality in the engineering profession.

OVERALL THIS PROJECT COMPLIES WITH THE ChE 487 EVALUATION GUIDELINE:

_____YES _____NO

_____NO, but the following extenuating circumstances make it acceptable:

Figure 1
The Code is taken seriously and considered part of the “Michigan tradition.” Timesheets are submitted under provisions of the Honor Code. This is made clear at the start of the term. They carry the student binding word that they are accurate. Time is recorded to the nearest half hour.

The data as utilized in this report has been manipulated slightly. The fall and winter terms has slightly different timing. Actual in-session time from assignment to submission of the project is nominally 12 weeks. However, many students do work on their projects during their break period. To accommodate these inconsistencies, the time span for the study has been uniformly adjusted to 13 weeks. This required combining some small fractions of weeks for both terms and the inclusion of study breaks within the term into the work time. This is not felt to place any bias on the overall results.

In addition, a few timesheets were missing. If these were for only one team member and were for a period early in the project, the student’s time for that month was entered as the average for the rest of the team. If data was missing for more than one team member or if that data was for the more variable end portion of the project, the data for that team was not used. In all, 31 teams were covered by the study period. Data from only 29 teams was deemed usable for analysis. For a few correlations, complete data was utilized for a lesser number of teams.

The data analyzed covers 3 school terms- 2 winter terms, 1 fall term. It covers a total of 115 students with senior academic standing, working in 29 design teams. There were 4 members in 28 of the team and 3 members in the other team. The teams worked on 9 projects with multiple teams having the same project. The assignment in all cases was to produce a technical design report, complete with appropriate engineering drawings and an economic analysis for one of the following facilities:

<table>
<thead>
<tr>
<th>ChE487</th>
<th>TIME SHEET</th>
<th>NAME</th>
<th>GROUP</th>
<th>MONTH</th>
<th>PROJECT</th>
</tr>
</thead>
</table>

### Figure 2
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T1H-13

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- Biodiesel Production (BDP)
- Diesel Hydrodesulfurization (DHS)
- Ethylene Oxide Production (EO)
- Manufacture of Sodium Carboxymethyl Cellulose (CMC)
- Itaconic Acid Production (IC)
- Acrylic Acid Production (AA)
- Biological Production of beta-Carotene (BC)
- Methanol Synthesis (M)
- Manufacturer of 1,3 Propanediol (P)

Missing data from BDP teams limited the amount of data from these teams used in analysis.

Work Input Variance Among Projects

Figure 3 shows the work variance found among 8 projects. Average work input varied from a low of 650 mhrs to a high of about 850 mhrs. The average for all teams on all projects was 783 mhrs. The mean for 28 projects was 780 mhrs. This is the approximate range that had been guesstimated as the work input requirement for project-12 to 16 hours per week per student. The data confirmed that the pre-assignment review procedure was doing a reasonable job of insuring a uniform work requirement among the projects.

Student time input on a major design project is not an issue, which can be well controlled by the instructor. To a very great extent, the design team is defining the problem. Their decisions control the course and difficulty of the design process. A series of student decisions can change the same basic problem from a 500-mhr assignment to a 1000 mhr assignment. Both end design might be equally valid. Both teams may have worked equally efficiently. But one design solution might have become tremendously more complicated than another. This is reflected in Figure 3. Project 1 shows a 50% variance between the highest work input team and the lowest. In fact the average max variance among teams working of the same project is 30%. This is higher than would have been predicted but not truly surprising due to the different design path student teams take.
Work Input Variance of Individuals Within Teams

The amount of work input variance by individuals within teams is much more uniform than would have been predicted. Figure 4 shows a plot of the variance within 26 teams. In almost every case, a “leader” can be identified who inputs about 10% more than other team members. Indeed teams are told to select a coordinator who will handle the administrative responsibilities. In most cases the highest inputs are made by these individuals. In a few other cases this individual may be the person handling the engineering drawings or writing the final report. Studies have not yet been made of what roles are played by those with the various inputs within a team. Individuals with the significantly low work inputs are, however, often identifiable by instructors as those who’s input is dictated by effort, NOT the role they play in the team. It is reassuring to note, however, that most individuals in most teams have a work input within 10% of the team average. In the majority of cases, students have achieved a responsible and equitable division of labor within their team.

Effect of Work Input on Project Grades

Grades for the individual projects were determined by the team Project Supervisor. All Supervisors graded to a common, written list of criteria. Each graded only teams who engineered the projects they supervised. All grades were reviewed in a joint meeting and adjusted as necessary. Uniformity of grading was very consistent as judged against a comparison of similar grades given for Oral Presentations on the project where all Supervisors graded all the presentations independently and then compared grades.

The students being graded all had senior academic status in chemical engineering. They were all in good academic standing and used to the nature of chemical engineering problems.
Intuitively most people would think that the more you work, the better the result. While this may be true on simple problems, it does not necessarily hold for complex projects. Figure 5 is a plot of project grade versus teamwork input for 29 teams. There is no apparent correlation in the projects studied. The lowest score received had the 4th highest work input. The highest score received was in the lowest 25% of team inputs. Clearly there are many factors that determine the success of a project; but beyond a certain basic minimal level, there is no discernable relationship between project grade and work input.

The nature of a specific project might influence the work-grade correlation. Figure 6 shows the correlation for 3 specific projects each designed by 4 teams. With the exception of CMC, again no correlation between work input and grade. More data would be necessary to determine if the CMC data does run counter to the overall correlation or is merely an aberration.

One other factor that was suspected to have a major impact on grades was the variance of workload within a team. It was felt that teams with a more uniform work distribution would produce better work. Figure 7 shows that this is clearly not the case. This is a plot of the work input variability for the 6 highest scoring teams and 6 lowest scoring teams in the study. There is little to distinguish between the two groups.

### Work Input over the Course of the Project

Students frequently complain about the excessive amount of work required by the Chemical Engineering Capstone Design Course. Yet most of the complaining occurs near the end of the course. Students are taught from the beginning that two of the essentials of good project management are good scheduling and a uniform, sustainable work pace. Most admit, after completion of the course that better planning and a more uniform work pace would have eased the work burden.

Figure 8 shows the weekly work input for 28 design teams. The average work input for all projects was 60 mhrs/wk (15 hours/wk/student). The majority of teams maintained a pace of less than 50 mhrs/wk input (12.5 hrs/student) for almost 2/3 of the project. Yet some were forced to invest over 250 mhrs (62.5 hrs/student) in the final week to meet the submission deadline. Bielefelt and Silverstein report similar work patterns in the capstone Environmental Engineering course at the University of Colorado. [8] Documentation of this trend should be an important teaching tool to give credibility to the need for scheduling and sustainable pace.
Effect of Team Input on Project Grade
Teams on Same Project

![Figure 6](image_url)

Figure 6

Effect on Grades of Variable Work Inputs within

![Figure 7](image_url)

Figure 7
Conclusions

Student project time sheets have proven to be a valuable tool in evaluating the uniformity of work required in projects assigned in the University of Michigan’s Chemical Engineering Capstone Design course. Findings from analysis of the work inputs of 29 teams working on 9 projects verifies that the Project Evaluation Procedure is reasonably effective as a pre-assignment screening tool to assure that design problems have uniform difficulty. For the University of Michigan’s Chemical Engineering Design course, the work input required for a project averages approximately 800mhrs. Per design team.

Analysis of timesheet data also shows that there is no general correlation between work input and project grade. Nor is there a correlation between variance in work input within a team and the resulting graded received. Fairness to individual effort aside, the success of complex major projects is NOT defined by time or distribution of group participation.

Future Work

Time sheet data can also be used to examine the elements that make up a project—meeting, material balances, engineering drawings, economics, report writing, etc. - to help define the elements requiring high work inputs. New and alternate methodologies can then be tried to reduce time inputs to that element. Studies on this use of time sheet data will begin in the near future.

References


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[5] CMSC 345 Syllabus, University of Maryland, Baltimore County, Maryland, 2006

