

## **AC 2008-2039: RATING CAPSTONE DESIGN STUDENTS ON AN INDUSTRIAL SCALE**

### **Vernon Ulrich, Grove City College**

Dr. Vern Ulrich has 19 years of design engineering experience in the printer industry working first for Xerox and more recently for Lexmark after earning a PhD in 1999. Since 2005, he has been an Associate Professor of Mechanical Engineering at Grove City College in western Pennsylvania.

# Rating Capstone Design Students on an Industrial Scale

## Abstract

Capstone design for senior engineering students is a required class that focuses on design projects for all students. Assessing a team's project results is usually a relatively easy task. However, fairly assessing the performance of individual students within the team is much more difficult. The complexity of the assessment task is compounded by the wide range of subjects, difficulty, and engineering tasks involved in differing projects. Assessing engineering performance across a variety of projects is also a common problem for most industrial employers. Many companies that employ engineers use a management-by-objective (MBO) assessment system for their professional employees. Grove City College capstone design students are now being assessed with a MBO system similar to industrial employers. A description of the Grove City College rating system including guidelines for writing student objectives and grading rubrics are presented along with an assessment of the success of the system.

## Introduction

Engineering capstone design is a course unlike any other course at Grove City College because the purpose of the course is for students to apply the knowledge they have gained across many of the subjects they have studied during the previous three years of engineering school. The goal is for students to have an opportunity to practice engineering in a team environment similar to the environment they are likely to experience upon graduation. A different type of class calls for a different process for assessing student performance than might be found in more theoretical courses. In their survey of engineering departments across the country, McKenzie, et al.<sup>1</sup>, suggest that many capstone design instructors find it easy to evaluate the performance of a senior design team, but struggle to evaluate the individual performance of students within the team. In an effort to assess the performance of both groups and individuals, Grove City College has adopted a management by objective process for individuals, similar to the process outlined by Tillman<sup>2</sup>.

Management by objective (MBO) originated from Peter Drucker in the 1950's. George Odiorne and others popularized the process in the 1960's. Odiorne describes MBO as "A process whereby the superior and the subordinate managers of an enterprise jointly identify its common goals, define each individual's major areas of responsibility in terms of the results expected of him[or her], and use these measures as guides for operating the unit and assessing the contributing of each of its members."<sup>3</sup> Much has been written both good and bad about MBO. Short provides a good summary<sup>4</sup>, as does Becal.<sup>5,6</sup> Regardless of the difficulties associated with MBO, it has been the experience of the author that most students will experience some form of this process immediately upon graduation from engineering school as they begin their first full time engineering employment. Therefore, the purpose for application of MBO to capstone design is threefold:

1. Provide a process for students and faculty to jointly define each student's role in the capstone design group.

2. Provide a process for faculty to evaluate individual performance on design projects.
3. Provide students with experience in dealing with a MBO performance appraisal process.

### **Setting Student Objectives for Capstone Design**

Setting objectives is absolutely critical to any successful MBO process. The objective setting process is presented in detail to the students in a lecture at the beginning of the semester. Students at Grove City College (GCC) are required to set at least one measureable individual objective for the semester. Individual objectives must<sup>7</sup>:

1. Be focused on a single job responsibility or outcome that will be completed during the semester.
2. Be reasonable – meaning that it contains a realistic amount of work for the student.
3. Fit in with the objectives of the other team members in that it represents something the student plans to work on to help meet the goals of the team.
4. Be measurable – both the faculty member and the student know when the objective has been completed.
5. Specify any constraints on the resources available to the student.
6. Have a completion date. (Objectives without completion dates can be procrastinated forever.)
7. Contain a weighting percentage. Students are expected to weight the importance of each of their objectives compared to the others. The weighting percentage should correspond to the percentage of time that the student expects to spend on this task.

Faculty advisors review and grade each student's objectives. The first submission is evaluated and returned to the student for revision. Students are expected to make corrections and submit their revised objectives to the faculty advisor. All objectives must meet the above criteria in order to be useful for the evaluation process later.

Consider the following example student objective:

#### **Individual Objective #1**

**Relative Weight 100%**

Description: Be the team finite element expert. Complete the finite element analysis of the frame and test the strength of the braking system on the prototype by 9/15/07.

The good news is that the objective is measureable, has a completion date, and a relative weight. However, there are significant problems with this objective. Consider the test of reasonableness. The team expects to start selecting concepts on 9/1/07. If the team has only started selecting concepts on 9/1, there is a near zero probability of the team completing the assembly design to the point of being able to complete a finite element analysis in only two weeks. Finally, and very importantly, the above objective is actually two objectives: finite element analysis and brake system testing. A corrected version of the student's individual objectives might read as follows:

#### **Corrected Individual Objective #1**

**Relative Weight 70%**

Description: Be the team finite element expert. Complete the finite element analysis of the frame and make a formal report of the results to the team by 10/30/07.

## **Corrected Individual Objective #2**

**Relative Weight 30%**

Description: Perform a test strength of the braking system on the prototype by 9/30/07. Present the results to braking team at next weekly team meeting.

There are some historic pitfalls to objectives of this type:

1. Students may sign up for tasks that sound interesting but they are not capable of completing. Hopefully, objective #1 does not belong to a student who has not enrolled the finite element course. Less obvious to the team, but possibly just as damaging to the end result, may be the student who signs up for objective #1 even though he/she received a grade of D- in the finite elements course.
2. A total focus on completing individual objectives may cause a student to complete them at the expense of the rest of the team, especially if there are limited resources that can be hoarded, such as software licenses.
3. Students may not bother to assist others on the team unless those tasks are listed on the student's individual objectives.

The first pitfall can only be warded off by the faculty advisor to the team, who needs to proactively work with the team and the student to suggest a new team role in which the student has a better chance of being successful. In order to deal with the second and third pitfalls, it is imperative that all students have additional objectives that represent the interest of the team and the institution. Grove City College uses four objectives of this type. They are modeled after similar objectives used a few years ago by a former employer of the author.

## **Objectives Required of All Students**

The following four individual objectives are required of all capstone design students at Grove City College:

1. Attitude: Student maintains a positive attitude toward assignments and teammates even when facing adversity. He/she approaches the job in a proactive way that contributes to a positive working environment for all team members. He/she demonstrates a willingness and ability to adapt and change to meet the needs of the team. He/she seeks a win-win approach to difficult situations.
2. Teamwork: Student is considered a valuable, contributing team member. He/she works effectively and cooperatively with customers, suppliers, team members, and advisors. He/she recognizes the value and maintains the dignity of others. He/she assumes ownership of responsibilities and follows through with commitments to the team.
3. Long-Term Perspective: Student acts as a good steward of all resources including the use of time, material, and assets. He/she demonstrates good judgment and acts in a way that benefits Grove City College. He/she strives to improve his/her own performance and also the Grove City College engineering department.
4. Interpersonal Skills: Student communicates effectively, openly, and candidly. He/she shares information and ideas in a constructive, courteous, and non-intimidating manner. He/she stands up for convictions and has the courage to express differing opinions without being offensive or argumentative. He/she listens well to other's ideas. He/she demonstrates mutual respect in all dealings.

## Evaluating the Required Objectives

Unfortunately, these four required objectives cannot be objectively measured since they are devoid of any objective measurement criteria! Furthermore, even a very astute and diligent faculty advisor cannot adequately keep track of the individual performance of all team members with regard to these objectives. Personal experience suggests that industrial managers are also unable to adequately observe the performance of their subordinates with regard to the above objectives. Thus, the assessment of the required objectives requires input from the student and from the team. Throughout the semester, it is incumbent upon the student to help their faculty advisor “catch” them exhibiting desirable behaviors. At first this process may seem odd, but sharing successes with a superior in order to create a positive image is often very important to receiving a good performance review in industry. This type of individual self-promotion runs counter to the training in proper personal behavior that many students receive from their parents. Therefore, self-promotion to a superior without being labeled as a patronizing gold-digger is a communication skill that requires some practice. What better opportunity to practice this skill than in capstone design?

## Rubrics for Faculty Evaluation of Objectives

At Grove City College, each of the four required objectives are scored by the faculty advisor on a four point scale. The categories for the scale, in order, are: Exceeded, Expected, Acceptable, and Needs Improvement. The required objectives are repeated below, for convenience sake, along with the advisor evaluation rubrics for each of these objectives.

Attitude: Student maintains a positive attitude toward assignments and teammates even when facing adversity. He/she approaches the job in a proactive way that contributes to a positive working environment for all team members. He/she demonstrates a willingness and ability to adapt and change to meet the needs of the team. He/she seeks a win-win approach to difficult situations.

The advisor’s evaluation rubric for Attitude is as follows:

Exceeded – Student is always cheerful and helpful to others especially in the face of personal and team adversity. Student believes that the team will succeed and is determined to make success happen. He/she goes out of their way to encourage other team members to succeed and leads by example. Student is proactive about starting tasks and excited about getting started on the next phase of the project.

Expected – Student starts and completes tasks in a timely manner. Student usually polite and helpful to others. Student occasionally encourages others. Student expects the team to succeed and acts accordingly.

Acceptable – Student is often polite and helpful. Student usually starts tasks promptly. Student may occasionally complain about assigned tasks, team members, or advisors but eventually gets the job done.

Needs Improvement -- Student exhibits one or more the following problem behaviors. He/she frequently procrastinates assigned tasks. Student undermines the team by making derogatory or demeaning comments about other team members, faculty, or staff. Student

constantly grumbles about assigned tasks and/or the time spent on them. Student expects team failure.

Teamwork: Student is considered a valuable, contributing team member. He/she works effectively and cooperatively with customers, suppliers, team members, and advisors. Recognizes the value and maintains the dignity of others. He/she assumes ownership of responsibilities and follows through with commitments to the team.

The advisor's evaluation rubric for Teamwork is as follows:

Exceeded – Student is indispensable to the team. Student puts in long hours, typically more than 15 hrs per week. Senior design is clearly a high priority to this student. Student consistently makes a strong technical contribution to the team. He/she often volunteers for difficult assignments and does them well. Student often lends a hand to other team members as needed. He/she considers the needs of the team and individual team members in making decisions. Student understands the importance of each member to the team and treats each team member with respect.

Expected – Student makes a significant contribution to the success of the team. He/she typically puts in 10-15hrs per week. He/she completes the tasks assigned by the team on or ahead of schedule. Student is helpful to others. Student understands the importance of each member to the team and treats each team member with respect.

Acceptable – Student makes a contribution to the team, puts in some time most weeks, and completes most assigned tasks on time. Student readily accepts assignments but may avoid difficult or time consuming tasks.

Needs Improvement – Student exhibits one or more the following problem behaviors. Student is frequently missing from team meetings. Time spent on senior design is not a priority, and student is seldom seen working on the project. Student does not finish tasks in a timely manner such that the team effort suffers. Tasks assigned to this student may need to be finished by others due to poor quality or lack of effort. He/she avoids assignments, especially those requiring effort.

Long-Term Perspective: Student acts as a good steward of all resources including the use of time, material, and assets. He/she demonstrates good judgment and acts in a way that benefits Grove City College. He/she strives to improve his/her performance and also the Grove City College engineering department.

The advisor's evaluation rubric for Long-Term Perspective is as follows:

Exceeded – Student goes out of his/her way to reduce the cost of the project. Student understands the importance of meeting project milestones on or ahead of schedule. Student improves the condition of GCC assets such as shop equipment. Student goes out of his/her way to ensure good working relationships with suppliers, other GCC partners, and the GCC staff and administration. Student contributes substantial ideas to improve the senior design course.

Expected – Student works to reduce project cost including searching for lower cost suppliers, reducing shipping costs, and ensuring non-payment of sales taxes. Student understands the importance of meeting project milestones on or ahead of schedule. Student is careful with GCC assets such as shop equipment. Student has a good working relationship with

suppliers, other GCC partners, and the GCC staff and administration. Student suggests improvements to the senior design course.

Acceptable – Student is concerned about cost, but does little to reduce expenses. Student is able to work with suppliers and other GCC partners. Student may not be particularly concerned about schedule. Student is usually careful with GCC assets such as shop equipment. Student is able to work with suppliers, other GCC partners, and the GCC staff and administration. Student leaves course improvements up to the faculty.

Needs Improvement – Student exhibits one or more of the following unacceptable behaviors.

Student continually spends more money than necessary to complete the project. Student is destructive of GCC assets such as shop equipment. Student offends suppliers, other GCC partners, or the GCC staff and administration and he/she fails to rectify the situation.

Interpersonal Skills: Student communicates effectively, openly, and candidly. He/she shares information and ideas in a constructive, courteous, and non-intimidating manner. He/she stands up for convictions and has the courage to express differing opinions without being offensive or argumentative. He/she listens well to other's ideas. He/she demonstrates mutual respect in all dealings.

The advisor's evaluation rubric for Interpersonal Skills is as follows:

Exceeded – Student goes out of his/her way to effectively communicate his/her thoughts about tasks and assignments. Student identifies subsystem interface problems and is proactive in approaching other engineers to reach a resolution. Student is proactive and timely in the resolution of conflicts and communication problems with teammates and advisors. Student frequently complements others on their successes. Student makes significant contributions to team meetings. Student has an excellent command of the English language always chooses words that are appropriate for the situation.

Expected – Student expresses his/her concerns about tasks and assignments. Student occasionally complements others on their successes. Student is able to resolve subsystem interface problems with other engineers. Student is able to effectively resolve conflicts and communication problems with teammates and advisors. Student contributes to team meetings. Student has a good command of the English language and usually chooses words that are appropriate for the situation.

Acceptable – Student seldom expresses his/her thoughts about the tasks or assignments. Student is able to effectively respond to subsystem interface problems raised by other engineers. Student is able to effectively resolve conflicts and communication problems with teammates and advisors. Student occasionally contributes at team meetings. Student's communications may have some difficulty with language usage.

Needs Improvement – Student exhibits one or more of the following problem behaviors. Student dislikes or has difficulty with assigned tasks but almost never discusses his/her thoughts about the tasks or assignments. Student avoids teammates and/or advisors. Student is unable identify and/or resolve subsystem interface problems. Student is continually involved in unresolved conflicts and communication problems with teammates and advisors. Student is generally silent at team meetings. Student uses inappropriate language.

## Scoring Rubric for the Individual Objectives

Individual objectives are also evaluated by the faculty advisor on a four point scale. The terminology for the scoring is: Exceeded Objective, Met Objective, Mostly-Met Objective, Did Not Meet Objective. The rubric for this scale is as follows:

Exceeded Objective – Objective has been completed ahead of schedule. Quality of work is above expectations. Objective was completed in the face of considerable adversity. Objective was a difficult or high risk assignment.

Met Objective – Objective has been completed as described and on schedule. Quality of work is good.

Mostly Met Objective – A reasonable effort was made to finish the objective, but something about the objective was not completely met, or the quality of work needs improvement.

Did Not Meet Objective – The objective has clearly not been met in some way. Perhaps, the quality of the work is very poor and/or there was a clear lack of timely effort to complete the objective. The student's team mates may have intervened and completed the objective in order to finish the rest of the project on schedule. There may other failures elsewhere on the team, but the most of the failure on this objective is directly attributable to the student.

## Assigning Numerical Values and Totaling the Score

Relative weights and point values can be varied by institution. At Grove City College, 30% is assigned to the required objectives and 70% to the individual objectives. The four levels for required and individual objectives are presently worth 100%, 90%, 75%, and 40% at GCC. These percentages result in a fairly generous scale, certainly more so than the industrial version familiar to the author. The reasoning behind this choice of scale is as follows:

- The scale is intended to be generous and help students learn to deal with this type of evaluation. MBO is an unfamiliar rating system to most students, although some of them will have experienced it during summer internships.
- Students who meet their objectives should receive a good grade. Meeting all of the objectives results in a score of 90%, which is the line between an "A" and a "B" at Grove City College.
- Students are required to do excellent work and exceed their objectives if they want to achieve an "A".
- Students are likely to miss an objective or two, especially if the objectives are aggressive.

Required Objectives Score= [(a x 100)+(b x 90)+(c x 75)+(d x 40)]/4

where:

a = #Exceeded

b = #Expected

c = #Acceptable

d = #Needs Improvement

Individual Objectives Score =  $\sum[(\text{Relative Weight for each objective}) \times (\text{Objective Score})]$

where:

Objective score = 100 for Exceeded Objectives

Objective score = 90 for Met Objectives

Objective score = 75 for Mostly Met Objectives

Objective score = 40 for Objectives Not Met

Final Total Score =  $0.30(\text{Total Required Objectives}) + 0.70(\text{Total Individual Objectives})$

### **Final Comments about Evaluating Student Performance on Objectives**

At Grove City College, the students are actively involved in the evaluation process. The required objectives for each student are rated by their peers on the team. This data is available to the faculty advisor to guide the advisor's rating of the student. Peer evaluation is announced in advance at the beginning of the semester and administered during class, usually as part of a test or exam and usually more than once during the semester. Students are also required to submit a written evaluation of their own objectives to their advisor prior to the advisor's evaluation of their performance.

Some discretion and generosity on the part of the advisor is often needed in the evaluation process. For example, an objective may not have been met due to problems difficulties well beyond their control, such as a supplier that does not deliver materials as promised, or a teammate who does not deliver on a commitment to complete a prerequisite task. Typically, such an objective should be abandoned and the relative weights adjusted accordingly. No one can perfectly predict the future, so a student's individual objectives may need to change to make them relevant to changing tasks. At GCC, the MBO process is only used to assign 30% of each student's final grade for the semester. Tests, presentations, and team evaluations, make up the rest of the grade.

### **Student Reaction**

Overall student reaction to MBO in capstone design has been positive. The positive reaction may in part be due to good salesmanship on the part of the faculty advisor. Some of the students have already had some experience with MBO outside of college and can readily testify to its relevance to the real world. Whatever the reason, most students agree that some form of goal setting and evaluation is necessary to the success of each project.

Students in the class were given a quick survey at the end of the fall semester in anticipation of this paper. There were 39 total responses. Table 1 lists the questions and summarizes the student responses to the questions.

**Table 1**  
**Student Survey Results**

<b>Statement</b>	<b>% Agree</b>	<b>% Disagree</b>	<b>% Blank</b>
MBO is worth doing	94.9	5.1	0
I like the process	79.5	17.9	2.6
It helped me focus on my role in the design group	79.5	17.9	2.6
It helped me focus on the tasks that needed to be completed this semester	71.8	28.2	0
I feel like I have control over my grade	79.5	12.8	7.7
I think it fits the real world	89.7	5.1	5.1
Overall, MBO should be kept	94.9	2.6	2.6

Students who took the survey also provided a number of positive comments such as:

- I believe it is good because you can focus on those goals. It also holds people accountable to their group members.
- The objectives are a great way to keep track of progress and motivate people.
- Project objectives really help to keep one focused on his/her responsibilities. It also creates accountability.
- It is an effective tool to encourage students to perform in order to meet their goals with the incentive of earning a good grade. It is comparable to the real world for creating incentive to meet goals without forcing the individual.
- Great, especially for defining my role in the group.

There were also some insightful student comments regarding some of the lower scores:

- I liked the process, but I feel like I had to figure out what my goals were before I knew what I was doing. Another week to figure out with the group would have been helpful.
- Only partly helped focus on tasks because, my tasks did change during the semester. I definitely enjoyed this objectives part. I think there should be a re-evaluation period halfway through the semester.
- Maybe less of a grade though.
- 3 and 4 are negative responses because I didn't accurately predict how my role on the team (as leader) would evolve. I also think objectives need to be tied to grades throughout the semester, rather than just at the end.
- Fix it, don't get rid of it entirely. Students have poor scope of what needs to be done. We're new to design projects! Did not help focus on roll in design group. How is this known so early? Roles must be fluid and adaptable.

### **Author's Observations and Comments**

- The message from the student comments seems to be that most students are convinced that objectives helped them define their role within the team, but many are frustrated with the need to try to predict the future. Attempting to predict the future is always the

problem with planning. Hopefully, some experience doing it in capstone design will help the students make better predictions in the future.

- Student satisfaction with the system almost certainly requires a student sense that the advisor has at least been fair, if not generous, with them individually. While the scale proposed in this paper, and used by GCC, favors success over failure, the scale can be as adjusted to any level of difficulty desired by the faculty. The reality of the MBO review process in an industrial workplace can sometimes be quite harsh. The end result of the evaluation process is usually a normal distribution of performance for the purpose of assigning pay raises. Since there is no extra pot of money from which to be generous, above average pay raises for star performers must be balanced by below average raises for other employees. Without the pressure to meet a payroll, faculty members can often afford to be a little kinder than industrial managers.
- Providing mid-semester feedback on objectives has always been a problem, since objectives are often not fully approved until nearly mid-term in the fall semester. In the spring, the process proceeds much more smoothly since the projects are well underway and the students are very familiar with setting objectives.

## Conclusions

1. Management by objective is not a perfect system, but it definitely has a place in industry.
2. MBO can be effectively used in capstone design.
3. The biggest drawback to MBO in the classroom is the time consuming nature of the evaluation process. Faculty advisors with large numbers of students will probably lose their sanity due to the effort required to maintain such a system.
4. The biggest upside to MBO in the classroom is the requirement that students define objectives and in the process define their roles within the design team. This process sets the framework for good team communication from the inception of the team.
5. The Grove City College MBO system is far from perfect. Such a system probably does not exist. The author plans to continue to refine the system in the future.

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