Using Industry-Accepted Management and Planning Tools in Teaching Engineering Analysis

Dr. Charles R. Glagola, P.E.
University of Florida, Department of Civil & Coastal Engineering

ABSTRACT

In conjunction with the implementation of the continuous improvement process by many US industries, a number of analysis methods or tools have been developed and successfully applied to engineering systems analysis. These management tools and methods used by industry present a very important opportunity for application in teaching analysis in both undergraduate and graduate engineering curricula.

Historically, students of engineering have been grounded in the scientific method as the accepted approach to addressing problems, not only in the basic sciences of physics and chemistry, but also in their engineering courses. This study shows how the management and planning tools used successfully by industry can be applied to analysis of engineering problems in the classroom as a complement to traditional approaches. By applying these analysis tools, engineering students can become more proficient in addressing the higher levels of engineering learning that encompass engineering systems as well as engineered components. This paper presents the results of the application of these management and planning tools in engineering classes and their affect in providing students with a more clear understanding of the practice of engineering by addressing the system rather than just the components of the system.

INTRODUCTION

Background and Analysis

Engineers working in industry have found that analysis can be quite different in practice than they became use to during their engineering education. Analysis ordinarily followed the "scientific method" that was instilled in high school on through the basic sciences of chemistry and physics required for engineering students. This analysis process served the students well when addressing individual problems, but much of the way engineering was taught in the past did not address the complicated interactions between processes. This, especially, when human factors were a required part of the process and had to be considered in an analysis approach. Basically, a "systems approach" was missing and was learned on the job by engineering graduates. Because of this deficiency in addressing systems and processes in engineering education, companies began to find methods which could be used by their engineers in putting together their technical skills with a vision of the complicated sequence of design and implementation necessary to produce the desired result.

Industry recognized early on that much of their leadership would rise from the ranks of their engineering staff. In order to make these engineers better managers and "whole-brain" thinkers, it was necessary to train them in seeing the whole process rather than the small techno-centered pieces of the big picture that they had learned in their undergraduate studies. A first step for industry was to adopt the statistical methods of Shuhart and then the more human-centered engineering of Deming and Juran which were so prevalent in the quality movements of the last decade (Burati). Am I suggesting that we are not teaching our engineering students to become good engineers. Certainly not, but I am suggesting that there has been the missing component of a systems approach that would allow our graduates to become more productive more quickly by being able to address the whole process rather than the parts of the process. As a disclaimer, most industrial engineering programs do have a systems approach to engineering, but that is because it is basic to the art and science of industrial engineering and, in reality, has been driven by industry and, perhaps, more so than other engineering disciplines.

Industry-Accepted Management Tools

Many companies that I have studied have used *The Memory Jogger* and *The Memory Jogger II*, from Gold QPC (Brassard) in developing their engineering staff, and it is these tools, not unique to Goal QPC or any other company, that will be addressed in this paper. A listing of the tools used in the case study and their application is shown in Table 1. Although there a many other such tools addressed in the referenced text, these are the principal ones that have been successfully implemented in the classroom.

TOOL	**PRINCIPLE FUNCTION**	**APPLICATION**
Affinity Diagram	Organize data	
Brainstorming	Develop solutions	
C&E Fishbone	Identifying causes and impacts	
Flowchart	Process definition	
Force Field	Identifying influence variables	
Matrix diagram	Identify relationships	
Nominal Group Techniques	Objective agreement	
Prioritization matrix	Selection of best option	

Table 1 - Analysis Tools

Learning Styles of Engineering Students

Engineering students ordinarily have a different learning style from that of the general student population. This may be environmentally conditions through the educational process or may be innate to students who gravitate to engineering, but most probably a combination of these influences. This learning style is "thinking" rather than "feeling" and "judging" rather than "perceiving." This learning style of engineering students falls within the classical objective type learning characterized by left-brain thinking (Wankat). Right-brain thinkers are those you would find in the arts and are more apt to see the broader picture rather than the individual parts of the picture that engineers would focus on. The objective of use of using the analysis tools as part of an engineering curriculum is to make engineering students become more "whole-brain" thinkers and begin to see more of the system that is composed of many processes rather than only a few.

Our objectives in the evolution of a student into an engineer should follow some plan. Bloom's taxonomy of learning provides an excellent approach for addressing how we should plan to address the learning needs for engineering students. Below in Figure 1 is the learning objective description developed by Bloom. This figure shows the evolution of learning through synthesis and evaluation. Too many of our courses are taught only through the first three levels of this leaning taxonomy when, with the addition of analysis techniques such as outlined in this paper, engineering students can be taken beyond the "application" stage of learning and develop higher level learning skills at the top of the order (Felder).

The higher level skills in the taxonomy of educational objectives are not ordinarily included in curricula for a number of reasons. The first reason is that engineering instructors teach they way they were taught. For bright creative people this doesn't make much sense, but historically, engineering faculty have had little or no training in teaching of any kind let along on how students learn, how to address learning needs, methods for improving leaning and addressing creativity. The second problem in reaching the higher levels of learning is probably due to the lack of training of engineering instructors in the methods by which we can better achieve these last three steps in the process. It has only been in recent years that our engineering academic community has been able to address these shortcomings through such professional societies as the American Society for Engineering Education and others. A great deal of knowledge related to engineering education was developed over the last decade by the National Science Foundation-sponsored Coalition of Schools programs which specifically targeted the need for reform in engineering education. Because of this new emphasis on the educational process, we now have a basis on which to build the educational process and, now, we have the tools that can be applied in reaching level 6 where our students will have learned how to "judge, select, critique, and optimize." In the Taxonomy of Educational Objectives we have the following components:

<u>Cognitive Domain</u>

Knowledge - Recognize or recall information
Comprehension - understand the meaning of information
Application - use the information appropriately
Analysis - break the information into component parts and see the relationships
Synthesis - put components together to form new products and ideas
Evaluation - Judge the worth of an idea, theory, opinion, etc. based on criteria.

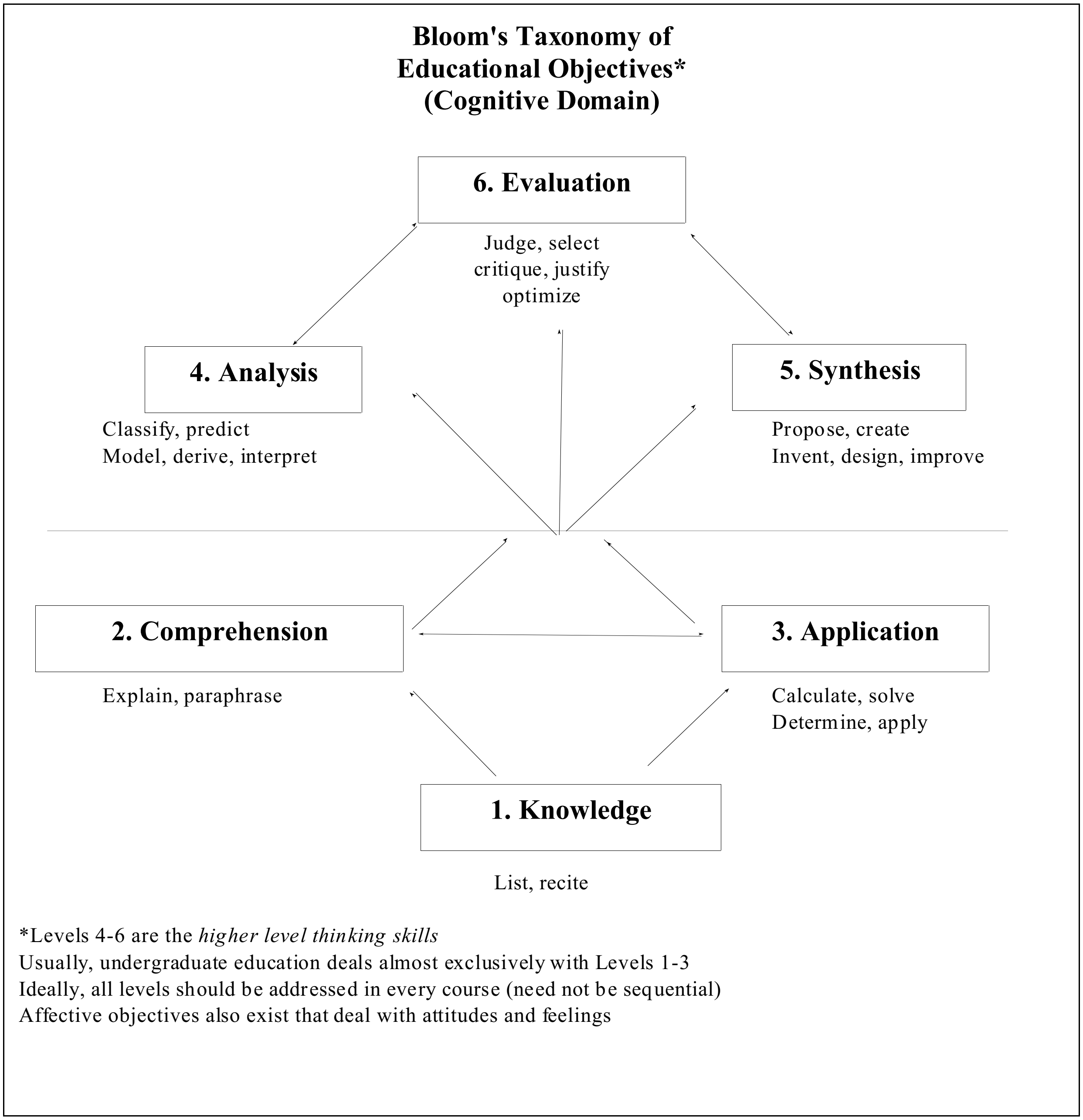

Figure 1 - Bloom's Taxonomy of Educational Objectives

The analysis tools used by industry apply to the higher level learning that is woefully absent in our engineering undergraduate programs and in many of our graduate programs. Table 2 shows the relationship between the analysis tools and the six categories of learning listed in the Taxonomy. Faculty who become aware of the higher level learning that is absent from the curriculum can use this as a guide in developing the course material around achieving higher level learning through their application.

Problematic to this solution is to educate faculty in the use of these analysis tools. Though workshops, conferences, seminars and other forums, faculty can made aware of this need as well as trained in the application of industry-accepted analysis tools.

TOOL	**PRINCIPAL FUNCTION**	**EDUCATIONAL OBJECTIVE**	**TAXONOMY LEVEL**
Affinity Diagram	Organize data	To classify, predict, model, derive, and interpret	4. Analysis
Brainstorming	Develop solutions	To classify, predict, model, derive, and interpret	4. Analysis
Cause & Effect Diagram (Fishbone)	Identifying causes and impacts	To classify, predict, model, derive, and interpret. Propose, create, invent, design, improve.	4. Analysis 5. Synthesis
Flowchart	Process definition	To classify, predict, model, derive, and interpret. Judge, select, critique, justify, optimize.	4. Analysis 6. Evaluation
Force Field	Identifying influence variables	Propose, create, invent, design, improve.	5. Synthesis
Matrix diagram	Identify relationships	To classify, predict, model, derive, and interpret. Propose, create, invent, design, improve.	4. Analysis 5. Synthesis
Nominal Group Techniques	Objective agreement	Judge, select, critique, justify, optimize.	6. Evaluation
Prioritization matrix	Selection of best option	Judge, select, critique, justify, optimize.	6. Evaluation

Table 2 - Analysis Tools Related to Bloom's Taxonomy

CASE STUDY

Value Engineering

A graduate course taught at the University of Florida in the Department of Civil engineering was used to test the industry-accepted analysis tools in the classroom. Students were required to purchase the Memory Jogger II as part of the text materials and these were used in training the students in the use of the tools. This text, widely used by leading engineering industries, provides an explanation of the Quality Control Tools and the Seven Management and Planning Tools used extensively in engineering analysis and decision-making.

Introduction and Exercises

Descriptions of the function and application of the tools are supplied in the text and provided the necessary information to allow the students to become familiar with and foundational with each of the tools outlined in Figures 1 and 2 within the first week of class. The text-provided exercises were supplemented with computer generated graphics of each of the tool showing the application sequentially developed using Powerpoint format.

At the beginning of this course, simple exercises were developed that addressed the function of each of the tools rather than their application to an engineering problem. These simple exercises related to everyday situations in which the student might find themselves such as an analysis of the problems in getting to class on time, or why their automobile may not start on cold mornings. These exercises were intuitive and easily understood by the students with regard to application of the analysis tools. Once the students became familiar with the function of the tools and had performed a few simple exercises, assignments developed. One of the first exercises that is presented to the students is to address the problem of determining, "How to Improve the Construction Engineering Program at the University of Florida." The students were first asked to Brainstorm solutions to this problem and then to use Affinity Diagraming to consolidate their extensive list into categories more easily addressed as specific topic areas for further consideration. Table 3 shows the results of the Affinity Diagraming. Students organized their Brainstorming results into the logical categories of:

- Program Enhancements Through Improved Resources
- Enhancing the Construction Engineering Experience Through Practical Application
- Enhance the Program Through Quality of Life Initiatives
- Review and Refine Academic Program
- Overhaul Curriculum
- Expand the Knowledge and Use of Computers in Construction Engineering

Table 3 - Affinity Diagram, Program Enhancement

Affinity Diagram - Logical sorting and ordering of results from Brainstorming process
Topic: How to Improve the Construction Engineering Program at University of Florida

Program Enhancements Through Improved Resources:
Reduce class size
More practitioners, less researchers
Student office space
More TA's
Better teaching facilities
More qualified professors
More faculty
Pay professors more

Enhancing the Construction Engineering Experience Through Practical Application:
CM Society
Field trips
Practical applications
Industry interaction
Student Mentoring program
Credit for practical experience
More plans experience
More hands-on
Career Forum
Better job placement
More professional guest speakers

Enhance the Program Through Quality of Life Initiatives:
Parking
Free football tickets
Don't pick on architects

Review and Refine Academic Program:
More required courses in CM
Combine with BCN/Business
Better relations with other departments
Raise admission standards
Refocus course curriculum
Increase credit hour requirements
Classes more than 1 time a year

Overhaul Curriculum:
Less emphasis on research, more academics
Include students in campus const. projects
Increase research proposals
Masters report more meaningful
Eliminate useless projects
More class discussions, less testing
More practical computer knowledge
International course
Case-study based curriculum
Public speaking course
More people skills (managerial)
Empower grad. Students

Expand the Knowledge and Use of Computers in Construction Engineering:
Access to Autocad
Seminar with software companies
Better computer resources

Assignments

Assignments were based on small portions of engineering projects at various stages of the project development. One exercise was to evaluate the engineering requirements for an intersection that was being considered for improvement. The students were first asked to develop a study that would identify the engineering needs related to the intersection as it existed. In this exercise they were to identify all conditions that existed and then to identify various parts of the intersection that could be addressed for improvement. They did this through Brainstorming and Affinity Diagraming. Having identified a list of categories of possible or desirable enhancements to the intersection, students were then tasked to use Cause and Effect Diagrams to determine influences each of the categories identified from the Affinity and Force Field analysis to identify the forces that were driving the team toward success for each of the functional areas that were identified, and those forces which were inhibiting reaching that success. From this, a list of good effects and undesirable effects were developed and then Cause and Effect diagrams were used to determine what causes could be assigned to our achieving the good effects and what were the causes that were leading to the undesirable effects. Table 4 shows a typical assignment. With the information in hand that was generated from these exercises, the students then went back to their Brainstorming and defined a list of possible engineering solutions to addressing the needs of the intersection. From this list, students then listed the both the possible engineering solutions and matched these against the criteria of desirable enhancements that had been previously developed. In addressing the enhancements, the students provided a weighted score for each after considering the importance of each enhancement to the specific needs of the community. The options were evaluated against the weighted criteria and a numerical score was derived for each possible solution.

Other engineering problems were addressed throughout the course and the tools were applied. This allowed the students to see how effective the tools could be on any engineering problem and how effective they were in gaining the valuable input from team members and producing the necessary data to allow for better decision-making.

CGN 5135
Value Engineering and Total Quality Management
Assignment #4
DUE: Tue 2/16/99

AFFINITY DIAGRAMING EXERCISE
Under the heading of the Issue which your group was assigned, list all of the ideas that you brainstormed and clarify the meaning of each.
Organize the ideas into an "Affinity Diagram" with a logical summary heading for each of the organized groups.
Summarize the exercise and how it was beneficial in defining, understanding, etc. the issue.

CAUSE AND EFFECT DIAGRAM EXERCISE

Take one of the summary headings that you generated in your affinity diagraming exercise
List the effect that is of interest
List the major causes (bones) that will contribute to the effect
Determine minor causes that influence the bones
Progressively reduce the causes to lower levels until you are satisfied that you have addressed the problem.
You may find that in working through this exercise you have located a conspicuous or "root cause" on which it would be helpful to perform an analysis using affinity or cause-and-effect diagraming.
Draw conclusions and recommendations from this exercise and include in the report.

Table 4 - Typical Assignment

Term Project

Two different term projects were developed around engineering projects located nearby. The projects were for: 1) a major addition to the Journalism Building on campus and the other 2) was a project to investigate alternatives to a new bridge over I-75 in Gainesville that was supplied by the Florida Department of Transportation. Students were divided into teams and were allowed to select which of these projects they wanted to develop. Term projects were divided into components starting from feasibility studies to final recommendations with students using the tools to analyze and decide throughout the development. Student teams were then required to make final presentations of the results of their efforts and present these before a group of fellow students and industry representative. Table 4 shows the term project assignment broken down into segments using the analysis tools.

TERM PROJECT REQUIREMENTS		
REQUIREMENT	**ANALYSIS TOOL TO BE USED**	**BLOOM'S TAXONOMY EDUCATIONAL OBJECTIVE**
Define Problem Statement	Brainstorming Affinity Diagram	Analysis & Synthesis
Define Objectives	Brainstorming Affinity Diagram	Analysis & Synthesis
Define Possible Alternative Solutions	Brainstorming Affinity Diagram Cause & Effect Diagram	Analysis & Synthesis
Define Constraints	Force Field Flowchart	Analysis & Synthesis
Define Criteria to Be Met	Brainstorming Affinity Diagram Force Field	Analysis & Synthesis
Define Resources and Responsibilities	Matrix diagram	Analysis & Synthesis
Select Top Three Alternative Solutions	Prioritization matrix Nominal Group Techniques	Synthesis & Evaluation
Develop an Implementation Plan for Each Alternative	Cause & Effect Diagram Flowchart Prioritization matrix	Synthesis & Evaluation
Prepare a Presentation of Alternatives	Include your analysis for all of the steps	Evaluation & Evaluation

Table 5 - Term Project Requirements

Student groups were required to use all of the analysis tools on the term project. Each of these assignments were done in conjunction with other considerations that were part of the project. Some of the other requirements that were supplemented by application of the analysis tools were: Cad drawings, specifications, functional evaluations of major project components (using other tools), schedules, contract documents, and others.

Student Feedback

The students who had never seen this type of analysis were duly impressed with their power. Some students had seen and used some of the tools before, particularly the Brainstorming, but had not had experience with the others. Students were asked to evaluate each of the tools in regard to their benefit on an engineering project. All of the students indicated that they would use the tools on all of their project in the future and were looking forward to being able to test this application in other engineering courses that they were taking. At this point, there is no data or feedback regarding the students' application of these tools in other courses, but casual conversations with some students indicate that they are extremely pleased with their transfer of these tools to other courses.

GENERAL APPLICATION IN ENGINEERING ANALYSIS

It is felt that the tools presented in this paper can easily be applied to undergraduate engineering courses where they will help fill the void in achieving the higher level learning that seems to be missing from many of our curricula now. Engineering students, from early exposure to the power of these analysis tools and how they can provide the synthesis missing in classical engineering education, will be able to apply this new knowledge to other engineering design courses during their educational experience. The application of these tools will help show the engineering student that the reality of engineering practice is in being able to make choices. They will understand that engineers are given a higher and more distinguished place in society for their ability to determine the best course of action and their ability to make the better decision.

RECOMMENDATIONS

Engineering faculty should be provided with training in, at least, the availability of these types of analysis tools if not formal training in their application and use in engineering classrooms. Students should be introduced to these tools early in their academic careers in order to achieve the higher levels of learning required for engineering practice as defined in Bloom's Taxonomy. University colleges of engineering who have, or are considering, development of freshman engineering programs or introductory design courses should seriously consider including training in the application of analysis tools for complete project implementation. Teaching engineering as a system that encompasses many subjective as well as objective processes and considerations is necessary for producing creative, competent, and confident graduates. By completing the circle of learning through Analysis, Synthesis, and Evaluation, engineering students will become much more productive members of the professional community and, perhaps more importantly, will leave school with a better understanding of the importance and the application of the knowledge gained in all of their engineering courses having been provided with this systems approach to engineering education.

Bibliography

Bloom, B.S., and Krathwohl, D.R. (1984). *Taxonomy of Educational Objectives. Handbook 1. Cognitive domain*. New York: Addison-Wesley

Brassard, Michael and Ritter, Diane, *The Memory Jogger II*, GOAL/QPC, Salem, NH, 1994.

Brassard, Michael, *The Memory Jogger +, 1st Edition*, GOAL/QPC, Salem, NH, 1989.

Burati, James L. and Mathews, Michael F., "Quality Management Organizations and Techniques", Construction Industry Institute, Source Document 51, August 1989.

Felder, Richard M., and Brent, Rebecca, "Effective Teaching Workshop," Southeastern University and College Coalition for Engineering Education of the NSF Coalition of Schools, 1998.

McKeachie, Wilbert J., *Teaching Tips*, Houghton Mifflin Co, Boston, Tenth Edition, 1999.

Sharp, Julie, Harb, John N., and Terry, Ronald E., *Combining Kolb Learning Styles and Writing to Learn in Engineering Classes*, Journal of Engineering Education, April 1997, Vol. 86, No. 2, pp. 93-102.

Wankat, Phillip C., and Oreovicz, Frank S., *Teaching Engineering*, http://Che.www.ecn.purdue.edu/ChE/News/Book/.

Woods, Donald R., et al, *Developing Problem Solving Skills: The McMaster problem Solving Program*, Journal of Engineering Education, April 1997, Vol. 86, No. 2, pp. 75-92.

BIOGRAPHICAL INFORMATION

Dr. Charles R. Glagola is an associate professor of civil engineering at the University of Florida where he has been working since 1994. Dr. Glagola received his bachelors degree from Texas A&M University, his masters degree from Auburn University, and his doctoral degree in civil engineering from Clemson University. Dr. Glagola has been involved in many engineering educational activities including chairing the Faculty Development Group of the Southeastern University and College Coalition for Engineering Education, SUCCEED.

Prior to joining the faculty at the University of Florida, Dr. Glagola worked in industry where he was the owner and CEO of a construction firm in Pensacola, Florida. He is the co-author of "Engineering Economic and Cost Analysis" and is currently the chairman of the publications committee of the Principles and Practice division of the American Society of Civil Engineers, ASCE.