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Abstract

One definition of creativity is the conviction that each and every existing idea can be improved. It is proposed that creativity in an engineering design process can be encouraged by the adoption of Total Quality Management methods based on a commitment to continuous improvement. This paper addresses the introduction and application of TQM philosophy within a freshman course on engineering design. Incorporation of TQM principles is demonstrated in a CAD/CAM student design process. The design centers on the creation and evaluation of a ship using commercial software. Once designed, the vessel is manufactured and tested in a water channel to quantify the performance. With very few constraints on the design and the direct application of TQM techniques, the student's creative abilities are tapped, channeled, and utilized.

Introduction

Before one can identify methods to stimulate creativity and innovation in the engineering education system, a clear understanding of the meanings of "creativity" and "innovation" is in order. As documented by Hueter[1], this topic alone can be the subject of an entire paper. Though not intended to be definitive, Hueter's work can serve as a source of possible definitions, to wit, "Creativity, as it is viewed here, concerns the evolvement of ideas, particularly how to do things differently and better; how to develop unique solutions to problems." This initial definition for creativity is later expanded as "Creativity is the process of thinking of something new, something that has not been thought of before." The creator is an optimist, "who is convinced there are better ways to do a job, who <u>knows</u> everything can be improved, who <u>knows</u> there are answers to every question and solutions to every problem, and who <u>knows</u> there are answers somewhere." He further adds, "The underlying key to knowing where creativity can be applied is in not being satisfied with things as they are, in recognizing that almost anything can be improved. Without assuming this attitude, chances are very slight that you will ever recognize opportunities to be creative."

As indicated by these strong statements, combined with the constant challenge presented by the global marketplace, the necessity for creative skills in engineers is clearly established. The question remains as to how can these traits be developed in today's engineering students? As challenged by Hueter, there is a need to identify and develop techniques to encourage creativity and, in essence, more fully utilize the students' natural abilities. Though not a panacea, one possible approach to answer this challenge is the adoption of Total Quality Management principles in our classrooms and laboratories.

Using Total Quality Management to Foster Creativity

The adoption of Total Quality Management (TQM) to foster creativity is suggested by a review of the critical terms in Hueter's explanation of creativity. Repeatedly, his definition suggests that things can be done better, we must not be satisfied with the status quo, and that everything can be improved. In short, this approach to the need for continuous improvement is the fundamental principle of TQM.

Though many explanations of TQM exist, an appropriate version has been recently presented by Green[2] as "TQM contains two main aspects: (1) meeting customer needs through continual process improvement and (2) a framework of tools and techniques to achieve this goal." This explanation describes the two components of TQM: the philosophy and the methodology. While TQM philosophy is fairly standard, each application of TQM requires a distinct subset of the large variety of tools which make up the methodology of TQM.

Though TQM has its roots in industry and government, the philosophy can be applied to any situation where a group of individuals is working toward a common goal. For such an approach to be successful, each member of the organization must share the attitude that all things can be improved, and each person must be given the opportunity to participate in that improvement. This structure of "bottom-up" participation is essential to fully incorporate the philosophy into the institution.

Meade[3] provides a snapshot of the applications of TQM within academia and his list includes the improvement of registration processes, accounting procedures, and other administrative functions. While these uses are important to improve each institution, he stresses that the philosophy has much broader and enriching implications if TQM is practiced in the classroom as well. The logic behind this challenge is simple: if the method is so good, why aren't educators using it more directly? The fact that the today's engineering student will most likely experience TQM soon after graduation provides an additional reason to expose them to the philosophy while still in school.

A number of educators have documented their response to Meade's general call for action, and of note are the papers by Chase[4], English[5], and Green. These educators have detailed teaching TQM in the classroom, using TQM to establish a vision for a department, and applying TQM to improve an entire course. This paper presents the results of another successful application of TQM: using the methodology to enhance creativity in a laboratory design project. For as noted by Hueter, the essence of creativity is the need for continual improvement, and this quest is the foundation of TQM.

Some Useful Tools from Total Quality Management

As stated, there are two components of TQM: the philosophy and the methodology. Though the philosophy of continuous improvement to satisfy the customer is standard for all applications of TQM, each application will probably use only a portion of all the possible tools to implement the philosophy. This section reports on some of the tools from TQM which have been successfully applied in a laboratory design environment. Though by no means inclusive, this list is merely a report of the methodology that was successful in one environment. This list has been developed from a variety of sources, most notably from the framework of TQM principles used throughout the Coast Guard, as well as from general ideas proposed by Peters[6].

Foundations of Quality

It is suggested that specific attitudes must be prevalent throughout an organization (lab section, department, institution, ...) to successfully implement TQM. Among the required attitudes is the belief that customer satisfaction is the driving force behind each and every action within the group. Thus, the organization must focus on the customer's needs and involve the customer directly in the solution process. Such an attitude demands that the TQM philosophy is believed by each member of the organization and that each member contributes to the continuous improvement process. To gauge the success of the process, some form of measuring customer satisfaction must be developed and used.

Design as a Process

The traditional method for improving a generic process is well suited as a guide for the more specific design process. The initial step is to **focus** on the need for the design, the criteria and constraints of the end user, and the mechanics used to create the design. Once the need for the design is understood and the designer is comfortable with the tools to create the product, the designer begins an in depth review of the factors that affect the performance of the actual design. During this **analysis** stage, the designer identifies the critical parameters which would have the greatest influence on the performance of the final product. The next stage is one of **development** where a number of designs are created. Once created, the various solutions are examined and a critical review process is used to identify the best design to meet the end user's criteria and constraints. The process is completed with the **execution** stage, where a prototype of the selected design is built and tested to quantify its performance.

Cooperative Learning

The necessity for team interaction exercises in the education system is well supported by the acknowledgment that most successful products in the market place have resulted from a team of developers. This emphasis on self managing teams in the design process is a continuation of the cooperative learning initiative to prepare our students for the conditions they will be expected to work in after graduation.

"Creative Swiping"

Using the phrase promoted by Peters, institutional support of creative swiping is acceptance of the fact that to achieve the best solution in the shortest time, one need not start from a blank piece of paper but rather examine all existing solutions to identify the most promising approach. From all existing solutions, the best components of each are identified, and those components are examined for their utility in improving the new design.

Support Champions

The completion of the design process presents an opportunity for acknowledgment of successful designs, and this acknowledgment can become a significant motivational tool. Creative ability can be tapped and developed by addressing the competitive nature of today's engineering students. If the design process uses the results of the execution stage to evaluate each group's design against each other, the student is given the chance to display pride of ownership, and thus be more motivated to create a champion design. This competition within a laboratory environment is another reflection of the actual conditions the graduate will experience in the market place.

An Application of the Method: Increasing Creativity in an Engineering Design Process

TQM principles have recently been applied to an engineering design course at the U.S. Coast Guard Academy (CGA). The Coast Guard as a whole has been using TQM since 1990, and many successful applications of the philosophy have validated the utility of the initiative. The CGA, as an institution, has applied the method to improve customer focus, communication, measurement, and recognition. Like most other universities, the early applications were concerned with administrative processes. Recognizing the potential for improvement beyond administrative procedures, a natural progression resulted in using TQM within the classroom to enhance the overall learning environment.

The basics of TQM are introduced to freshmen at the CGA in one section of the course entitled, "Introduction to Engineering Design" (IED), a required subject for all incoming students. This one semester course includes two hours of lecture and three hours of laboratory work each week. Besides TQM principles, the course covers topics such as the design spiral and introductions to naval architecture, civil, mechanical and electrical engineering. The laboratory sessions are primarily design oriented and reinforce the lecture subjects through individual and team projects, such as construction management, computer aided design of trusses, paper beam design, energy transfer and welding experiments, and ship design.

The most involved design project in the IED lab is a ship design exercise where the student strives to design a cargo carrying vessel that maximizes a performance criterion. During this segment, which totals more than twelve hours of lab time, the students are fully immersed in the complete design process. They first individually design and model their vessel on the computer, form teams to evaluate the various designs, and then manufacture the most promising model. Once built, each design is performance tested, and the best design from each lab section is identified.

TQM methodology has been applied throughout this process to improve the lab and to provide the student with an opportunity for 'hands on experience' with TQM. This experience reinforces the basics of the philosophy that are introduced in the classroom. The ship design lab was a part of the IED course before the advent of TQM at the CGA, and thus it is pointed out that this lab was not created based on TQM, but more importantly, an existing process was improved using TQM. The specific TQM tools which have been used to achieve that improvement are discussed in detail.

Design as a Quality Experience

The entire exercise centers on addressing the needs of the student while they satisfy the requirements for each lab period. With the need to understand basic naval architecture, a computer aided ship design software package, and the actual steps in the design process, the complete exercise can seem overwhelming at first. This statement is all the more true because of the makeup of the lab itself. Being a required course for all freshman, each lab group typically includes students majoring in civil, naval or electrical engineering, science, math, and management.

The goal of the lab is to create an interesting, stimulating, and enjoyable experience to illustrate the rewarding aspects of engineering work. The process succeeds because the exercise is broken up into individual components. A student's progress to the next step in the process is only allowed once competence in the current phase is demonstrated. This structure thereby establishes a clear time frame when the student should be learning the mechanics, when the student should be creating, and when the students should work as a team.

The ship design project begins with a **focus** on the mechanics and needs of the design. An entire lab session is devoted to learning the commercial software that will be used to design the ship on the computer. The student is led, using tutorial instruction, through all steps in the computer program. The emphasis of this first session is on learning the software. Only after the mechanics are understood can the actual design begin. The time devoted to learning the mechanics (software) is essential to diminish the inevitable frustration associated with using a new procedure. Later, the student is able to concentrate on *designing* the product, and thereby avoid using that *design time* to learn software.

The next stage of the design process is the introduction of the constraints and criteria for the ship that will be designed and built. The ship must be capable of carrying a cargo (1.5 kg mass) without submerging the deck edge. One constraint on the ship is that the model will be constructed from a solid foam block, therefore the size of the vessel is restricted to the size of a single block of foam (typically 60 x 25 x 10 cm). The only other constraint is that the design must be a single hull so it can be modeled by the software.

The design criterion is established using a performance ratio. One performance measure that has been used is the ratio of stability and safety to drag and cost. For completeness, it is noted that the stability factor used is the design's metacentric height, the safety factor is the height of the freeboard, the drag factor is two raised to the sum of the vessel drag at various speeds, and the cost factor is the weight of the final design.

Once the constraints and criteria of the design are introduced, the next stage of the design process, **analysis**, commences in the following laboratory session. From their prior experience, the student is aware that once a computer model is created, the software provides values for the metacentric height, freeboard, and weight of the vessel. As such, three of the four variables that establish the performance criterion should be known with a high level of confidence. The student is required to draw upon the classroom discussion concerning basic naval architecture to realize that the value of the drag variable in the performance ratio is not explicitly known without testing the model, but this value is a function of the vessel shape, waterline length, and wetted surface area.

Because the exact relationship between these parameters and drag is not known, the student must make an initial estimate of their influence on the drag. Through a careful review of these critical parameters, the student becomes aware of some of the many design tradeoffs. It is only after the student closely examines the variables which determine the performance factor can they estimate the relative impact of each design decision. The student is aided in their understanding of the significance of each factor by reviewing previous designs in the laboratory to get a feel for the relative importance of each parameter. By doing so, **creative swiping** is promoted and the student is encouraged to build on successes of the past to improve their own creation.

With a clear understanding of the factors that influence the performance criterion, the student returns to the commercial software to individually design any number of vessels. During this **development** stage, they are free to modify the designs on the computer to see how the performance factor changes as the design changes. The inquisitive nature of the student is tapped as they quickly and easily explore the question "what if ....?" in their search to find the best design. Once they have completed their own design, the students are grouped into teams of four to compare and contrast their individual designs. The goal of this **cooperative learning** experience is to identify that design which will maximize the performance ratio. They are required to use a decision matrix to evaluate the four independent designs, and the result of this stage is the selection of a single design for the group to build.

Once a design is chosen, the group enters the final stage of the design process: **execution**. As a group, they use the computer to transcribe the design onto full scale templates and these templates are used to manufacture the boat from a solid piece of foam. Again, an entire lab session is devoted to this process. The following lab session, each group's constructed boat is weighed, the freeboard measured, the metacentric height determined using an inclining test, and the drag measured using a circulating water channel. The resistance is simply measured as the drag force of the vessel at a low, medium and high speed. These physical measurements are then used to compute each vessel's performance ratio. The design that maximizes the performance ratio is designated as the champion design.

The design process is concluded by acknowledging the most successful design teams within each lab section. Formal **recognition of the champions** is accomplished by awarding a "Certificate of Excellence" to each member of the winning design team and by posting photographs of the team members and their designs in the hallway outside the laboratory. The response to this award system has been overwhelming. The students try very hard to get their picture outside the lab, and thus their interest and motivation in the project are strengthened by this simple recognition process.

Conclusions

The success of this program is most effectively measured by the students' response to the exercise. Overall, the students enjoy the experience, and the ship design segment is among the favorite sections of the course. The students are extremely motivated to see their individual design selected by the group, and later the entire group displays a high sense of enthusiasm to ensure *their* design does well against the competition. The exercise provides an additional educational benefit as the students physically construct something that they had previously created (and seen) on the computer. Such a link between computerized modeling and the real world does not often exist in their education. As we continue to incorporate computers in the education system, a greater effort must be made to establish such a connection between the computer and physical world.

The success of incorporating TQM methodology in the ship design portion of the IED lab sequence has been a motivating factor to extend its use to other laboratory sessions. The reoccurring theme of the IED course is the design spiral, and this theme is very similar to the mechanism proposed by TQM. Both processes follow the same general outline: define the problem, identify possible solutions, implement one solution, ... review its effectiveness in solving the problem. The fundamental difference of TQM is the process of continuous improvement upon which the philosophy is based. As such, the IED course and labs continue to be adjusted to provide the student with a world class introduction to the fundamentals of engineering.

If the essence of creativity is the conviction that things can be done better, creative abilities can be developed using Total Quality Management principles. This application of TQM methodology in a design environment has demonstrated that TQM techniques present a clear path for structuring the design process, promote the need for quality designs, and serve as a strong motivator. Though the application presented here was a ship design lab, the methods can be applied to any design process. An additional benefit of applying TQM in the labs is that the student has a chance to 'learn by doing' not only the engineering subject, but also TQM. By focusing on the student's needs in the design process, the project becomes an enjoyable experience for the student and the instructor, and thereby enhances the learning experience.

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