Int. J. Engng Ed. Vol. 12, No. 1, p. 26–35, 1996
Printed in Great Britain.

0949-149X/91 $3.00 + 0.00

Implementing Modern Product Realization*

G. L. FERGUSON
Department of Mechanical Engineering, The University of Alabama, Tuscaloosa, AL 35487-0276, USA
J. T. BERRY
Department of Mechanical Engineering, Mississippi State University, Starkville, Mississippi, USA

An intensive short course has been developed and taught that stresses the role of modern product realization as envisioned by the National Research Council's report on design modernization in the United States. This course had three primary goals: to introduce the student to advanced manufacturing processes; to integrate the undergraduate engineering science skills needed to conduct a comprehensive design-and-build project; and to expose the students to concurrent engineering design concepts and the vital need for effective communication. In order to finish the project in the allotted time, teams were formed with each student having responsibility for one of the requisite skills needed to complete the effort. Successful completion of the project required each team not only to design and document the design, but also to build and demonstrate a working prototype accompanied by the anticipated manufacturing plans. This paper describes the course content, philosophy, design problems used and results achieved.

INTRODUCTION

OVER the last several decades, the teaching of manufacturing technologies in the engineering colleges and universities of the United States has decreased dramatically, and the University of Alabama is no exception. Many reasons have been suggested for this decline and most relate to the 'machine shop' mentality summarizing the way the classes were historically taught. When manufacturing courses were taught, the philosophy was: 'Here is a metal cutting tool—now make this simple object'. Teaching a class in this manner was important insofar as the student had a hands-on experience and became somewhat familiar with manufacturing terminology, machine limitations and the problems that skilled tradespeople might encounter. However, this approach did little towards teaching innovative design and integrating that design and its manufacture into a cohesive process.

As American curricula moved away from manufacturing-related courses, even at this basic level, many schools sent what shop facilities they had to salvage. As a result, little equipment now remains in place to supplement teaching fundamental manufacturing processes. Aggravating this has been the rapid advancement in materials science, manufacturing technologies and processes, and changing management philosophies. The materials revolution has yielded composites, ceramics and specialty engineered materials. Manufacturing advances have given rise to flexible or agile manufacturing cells, automated and robotic controls, autonomous supply carts and rapid prototyping. Manufacturing project management has resulted in just-in-time (JIT) material suppliers and computer-assisted process planning (CAPP) programs. Exacerbating the situation is the changing corporate management and design philosophies enveloping the entire product realization process. Quality function deployment (QFD) has emerged as a technique developed by the Japanese to bound design problems by systematically soliciting and refining customers' needs into functional engineering constraints. Total quality management (TQM) is a general management philosophy to ensure overall quality throughout the product's lifecycle by assuring that quality compliance is incorporated at each stage of the realization cycle, not just at the end as a statistical process control. In this context, QFD becomes a useful method within the confines of TQM. Most young engineering students are ignorant of even the basic machine tools such as lathes and mills and their capabilities, much less have any understanding of such advanced technologies and management philosophies.

The last several years has seen a tremendous effort to explain why America has lost its economic competitiveness in the global marketplace. These studies have concluded that the basic design process practiced in this country is at fault. The recent National Research Council (NRC) report [1] on design effectiveness best summarized the situation by asserting that 'The lack of teaching and practicing design for manufacture is now recognized as the root cause for our lack of economic competitiveness. The solution is to revamp how the design process is taught and practiced in this country.'

---

* Accepted 15 July 1995.

This message is echoed by ABET's requiring engineering curricula to be restructured to emphasize 'vertically and horizontally integrated' design. Concepts such as simultaneous or concurrent engineering or design for manufacture are suggested as possible means to this end. The problem with modifying the design process as currently practiced is that it is misunderstood by most American practioners and educators of design. To implement any changes in the design process, the existing process must be understood and then a consensus reached on what it should be.

At present, a majority of US firms still practice the traditional serial design process which does not consider manufacturing implications on that design. Dixon [2], Shigley [3] and Medland [4] are but a few who have spent time identifying the existing design process. In essence, three basic design phases were highlighted. Although different terminology was used to describe the three phases, they were, in essence, the same. The defined phases were:

Phase	Dixon	Medland	Shigley
1	inventiveness	concept	synthesis
2	analysis	analysis	analysis
3	decision making	scheming	presentation

Noticeably lacking from the list of phases is that of problem definition, or the bounding of the design and production constraints. In the past, it was generally assumed the problem was well defined prior to engineering efforts beginning. It is now recognized this is not necessarily true and the consequence of this assumption is reflected in ever-changing designs as the constraints evolve. In fact, Solomon [5] concluded that a design problem is only well defined at the end of the problem-solving process, since part of the problem is the discovery of constraints that bears on the outcome. Furthermore, the various phases have some overlap and are iterative. That is, if some aspect of the phase 1 concept is invalidated during phase 2, then phase 1 has to be revisited. The NRC report suggested that the engineering schools in the USA have admirably taught students the analytical skills needed within phase 2. However, the phase 3 skills development are weak, while the conceptualization phase is where American education is truly lacking. Dixon [6, 7] suggests this is due to intellectual stagnation in the American mechanical design education and stems from the fact there is not a consensus, in the USA, of what constitutes conceptual design. Dixon concluded that academe and industry should study current best practices and cognitive design fundamentals and then teach and practice them. In this context, including problem definition, design education must fully span the four phases of design: identification, conceptualization, analysis and implementation. It cannot just encompass the last two as has often been the case.

Simply improving student skills in conceptualizing solutions will significantly quicken the traditional design process, but it still will not incorporate other disciplines into the process without use of a systematic approach. Hence, truly optimal design includes such disparate disciplines as engineering, marketing, manufacturing and management in an interactive and concurrent process that begins at the problem onset, in the product definition phase. At present, in America, a systematic approach to practicing and teaching concurrent engineering under this format does not exist. This may be partially due to American arrogance that no one else can solve the problem except us, so we refuse to look elsewhere. As ineffectual as it may be, trial-and-error experimentation is being undertaken to find workable solutions. Many large American companies are experimenting with ways to integrate design and manufacturing components earlier in the design phase of the product lifecycle. A *Mechanical Engineering* magazine [8] article noted that several industries along with ARPA (formerly DARPA) had formed a consortium to investigate ways of accelerating the design cycle. Limited successes have been achieved at defining so-called 'best practices' through the trial-and-error approach, but still not enough is known for them to be fully exploited, as evidenced by the many recent manufacturing conferences devoted to this issue. [e.g. 9] Several graduate programs have developed over the last few years that team business and engineering students for a practical master's degree which emphasizes enterprise programs and internships [10, 11]. The limitation with this format is that the majority of American engineering students forgo graduate school, hence such information takes even longer to reach the levels at which it is most needed.

To revitalize American industry, the engineering curriculum must be revamped to teach and practice a 'hands-on' concurrent engineering process taught by knowledgeable engineers with industrial design experience. A major drawback is that many American engineering design educators are really engineering scientists without design experience. The question becomes: how is this to be accomplished in light of there being an insufficient supply of 'engineers' as opposed to 'scientists' to teach design? Compounding this has been the lack of definitive textbooks on the subject for use in education. Dixon and Poli's [12] recently published book will help alleviate the later concern. This paper details the first two attempts at teaching a modern product realization course at the University of Alabama using 'engineers' with industrial design experience.

BACKGROUND AT THE UNIVERSITY OF ALABAMA

The College of Engineering at the University of Alabama has for several years had a manufacturing certificate program. This course of study included traditional classes from the industrial, mechanical, and metallurgical engineering departments. Such classes concentrated mainly on the automation topics, i.e. robotics and graphics, where the subject matter was relatively easy to exploit in practice. However, studies of American factories have shown that simply automating the factory floor only minimally affects total product cost, since often no more than 20% of the product cost is directly related to labor and this is what automation addresses. On the other hand, the initial design phase, as traditionally practiced, represents about 5% of the product cost but ultimately controls 80%, or more, of the cost spent in manufacture [13, 14]. Implementing a systematic approach to concurrent product and process design at the problem identification phase will help minimize the number of design changes needed for part producibility.

The curriculum format mentioned is found at many schools where the emphasis has been, and still is, on the tail-end of the serially practiced design, e.g. analysis phase, and build process. In fact, many schools still do not introduce manufacturing processes. If they do, it is usually from a process standpoint without a focus on design or designing for manufacturability. Therefore, American efforts to teach *and* practice worthwhile engineering design have been unsuccessful, resulting in students still not able to synthesize solutions and integrate the specific engineering sciences into a product design strategy. Even if schools wished to correct the situation, they will experience significant difficulties in so doing. The problem is exacerbated by the lack of engineering educators experienced in industrial design settings, meaning that the resources needed to implement such a modern practice-related course rarely exist in the university environment. Recent faculty additions at the University of Alabama have helped remedy the situation.

COURSE OBJECTIVES

The objective of the course was to provide a meaningful hands-on experience that encompassed the spectrum of topics needed to *conceptualize* and *produce* a successful design during a typical 5-week summer session. The specific objectives are best summarized in three broad areas:

- introduce the student to advanced manufacturing processes;
- integrate specific undergraduate skills and knowledge needed for design; and
- expose students to the full design process as it applies to concurrent engineering and increased communication needs.

The implementation of these objectives required they be broken down into several topical areas involved in the design process. Among the major areas reviewed were:

- Design process from definition to presentation
- Brainstorming as a conceptualization tool
- Computer-aided engineering and design tools
- Materials: selection, manufacture and parts procurement
- Manufacturing processes, both manual and automated
- Modern communication skills

Noticeably lacking from this list are project and business management topics, engineering economics, financial and marketing concerns, legal issues, and facilities and process planning. Engineering economics was not covered as a separate topic but was woven into the text of the other topical areas. The others were omitted for two primary reasons: insufficient time to incorporate them in such a short course; and a lack of students whose background in these areas allowed for their incorporation into the project teams. Ideally, any real concurrent engineering experience would include individuals with these skills and would start at the problem definition.

DISCUSSION OF OBJECTIVES

As indicated, many topical areas were introduced as part of this course. To convey this information efficiently in a meaningful manner during such a short time required the course be structured in three parts (see Fig. 1). The first two parts consisted of lecture periods and directed laboratory sessions co-ordinated with the lectures. These were conducted during the first half of the course at the university. The last portion of the course was an intensive hands-on experience in a manufacturing setting stressing the realization of the design as a prototype. The Bevill Center for Advanced Manufacturing Technology, located 125 miles away in Gadsden, Alabama, was used as the setting for this part of the course.

What follows is a brief discussion of the major topical areas presented and how they were implemented in the course. As a side note, these topical areas were introduced as they applied to the specific design problem given to the teams. The implementation of the design and build process

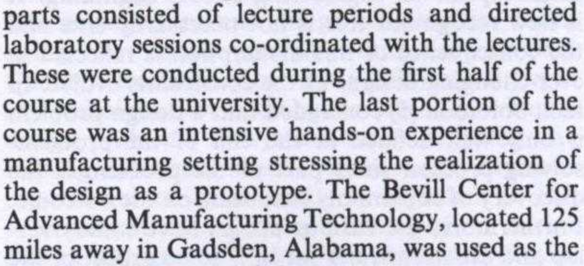

Fig. 1. Course depiction.

was to form teams representing competing companies who had been contracted to produce a working prototype. The philosophy was that the company with the 'best' prototype would win the follow-on, large-scale production contract. To win, a manufacturing plan and economic analysis were required to determine if mass production was not only feasible but profitable. To date, two design projects have been accomplished. The first involved the design and build of a small hand-operated mechanical handpress, and the second redesigned a car jack to include a winching feature to be sold as an option for the new Mercedes-Benz All Activity Vehicle to be manufactured in nearby Vance. In addition, several artificial constraints were added. These included end item cost and at least one cast component. Both project descriptions are included at the end of the paper.

Design process

Recalling the NRC report findings, most US engineering schools are very adept at teaching the analysis phase of design, but traditionally ignore the portions of the design process devoted to problem definition and developing concepts that will be analyzed and refined. Under the present ABET 'bean counting' mode of design content, typical design problems consist of 'canned' problems missing a small amount of necessary information. The student ascertains what is missing from such 'open-ended' design problems and then applies cookbook formulas to generate a single, correct answer. This is analysis, not real-world design.

To move the student beyond this concept of design, the first lectures centered on what is design, how is it practised in the USA, and what should we be doing differently. It was stressed that the first phase is problem identification, but in America this step has often been considered optional. Hence, many problem statements have been driven by non-engineering functional requirements, e.g. aesthetics or cost over functionality. The students quickly realized that for successful product identification, the engineering and manufacturing functions had to assist the business and marketing personnel in the development of the bounding constraints. In fact, this was the planned structure for the second offering of the class where parallel courses from business and engineering could be cross-linked. No business students partook of their class, so this attempt at concurrency was not acheived. During these lectures, QFD was mentioned as a tool to aid in deriving the functional constraints for the problem. This subject matter was not developed due to the intense time constraints coupled with neither faculty being well versed in QFD techniques. Rather the problem statement given to the students had bounding functional constraints embedded. During the conceptualization phase, the students were led through a process to ferret out the constraints for use in developing the concepts.

Brainstorming

Once problem constraints are understood and before any analysis is conducted, conceptual solutions must be developed and refined for analysis to proceed. Traditionally, schools have not attempted to introduce concept generation to the students, as few faculty are experienced at this. Many people consider conceptualization to be an abstract thought process that cannot be taught. Hence, they ignore it. Crossley [15] was an early pioneer in developing a systematic approach to conceptualizing. He suggested a function-first decomposition method where abstract functional statements were developed to suggest methods of decomposing the problem into sub-problems. The sub-problem then had relevant abstract functional statements developed to decompose the problem further. This continued until the lowest problem functional statement was developed. As each level progressed, the functional statements usually became more technical and less abstract.

Other recognized systematic concept generation methods include:

- examining potential use of alternate physical laws to achieve a given function;
- use of alternate concept generation schemes such as brainstorming;
- literature searches to see if others have attacked similar problems; and
- personal experiences with similar situations.

This course required the students use all appropriate methods. Since none of the students were familiar with brainstorming, this technique was chosen as a laboratory exercise to help in developing concepts. Even though students are unaware of brainstorming as a technique they often practice it unknowlingly. A recent course at Stanford University [16] stressing reverse engineering as a design tool revealed that the students practiced a form of brainstorming to develop concepts about why a mechanism worked the way it did. However, the brainstorming was unstructured and not geared toward new product design.

It is for this reason that many companies hire professional facilitators to lead design teams through the process of structured brainstorming to aid in concept generation. The concept of brainstorming is to trigger ideas through free association using a general suggestion. During the brainstorming session, no idea is rejected as nonsense. Often, off-the-wall ideas trigger other thoughts that might develop into a valid solution. Later, the group is reconvened and the ideas generated are critiqued and bad ones eliminated. The express purpose of this exercise is to stress not forming any preconceived solutions to a problem, but to examine the problem in the most general way possible (in this course in terms of the abstract functionality statements).

To facilitate the effort no initial design parameters were given to the students in the problem statement. This was intentionally done to prevent the students from blindly starting a design analysis based on a faulty preconceived concept. The participating instructors acted as facilators and led the conceptual design efforts for each team. This forced the design teams to think about general concepts (the abstract functionality statements) instead of specifics. For instance, with the handpress project, the students were familiar with a rack-and-pinion hand press from another course and were ready to begin their design immediately based on this concept. However, the students were aided in deriving the functional requirements during the session devoted to brainstorming. In this case, the developed functional was: something is needed to exert a controlled force in a specific direction. This led the students to the question: how can this be done? This led to several different mechanical systems, e.g. gears, sprockets and chains, pulleys and belts or cables, the rack and pinion press, screw presses, and others.

To reinforce the conceptual design stage, the students were given the task of developing sketches of at least three of the potential concepts from the brainstorming session and assessing the advantages and disadvantages of each. Based on their critique, they selected the idea they deemed best. To validate their critique process, each team made a presentation to the class about the generated concepts and why a specific concept was chosen.

Computer-aided engineering and design tools

As part of the curriculum at Alabama, students are required to take a freshman drawing class, part of which utilizes AutoCad® to teach computer-aided drawing. This knowledge is never formally put to use in the rest of the curriculum. This is disconcerting, as some software vendors are suggesting that drawing databases are the central concept behind concurrent engineering, at least during the last two stages of the design process where the detailed design has progressed to the point of supporting finite element analysis and manufacturing planning. The advance of solid modeling software is an important step forward, not only as a support tool for analysis, but also as a tool that can be used to support conceptualization. It may eventually allow disparate disciplines to visualize concepts as they are being suggested during problem definition meetings. This will allow discipline-specific terminology, which has been a hindrance in the past, to be eliminated in favor of a visual object all can understand. As such, it is imperative the students refamiliarize themselves with computer-aided design tools and the role they play in the design process.

Although not used, the students were also exposed to the existence of other computer-aided engineering tools, such as rapid prototyping and finite element analysis. For instance, examples of finite element analysis results were displayed for the students to understand the linkage between modern analysis tools and design. Since none of the students were experienced in finite element analysis usage, its usage was not required as part of their project solution. Rather, all analyses were performed by hand to validate that design parameters had been met. However, computer-aided analysis would have been most beneficial to the students in this effort and other curriculum courses such as the senior-year capstone design project.

Materials: selection, manufacture and parts procurement

One of the most important parts of the engineering design process is the selection of materials to be used. Many students have never been involved in any material selection process. In these projects, the students are constrained to use at least one cast part. This required they learn about casting in general, and iron or aluminum casting specifically. The initial project centered on iron casting, its processes and the various properties that might be obtained based on the grade of the resultant cast iron. In this case, the intended cast material was ductile iron (grade 65-45-12).

As part of the casting process, the students were required to design and produce drawings of the pattern utilized to make the mold, thus requiring the student to understand gates, runners, risers, etc., in order to correctly control pouring shrinkage. They also interfaced with the pattern makers to ensure the patterns were completed correctly and on schedule. Finally, they assisted in the foundry during the actual pour. A sample of the cast material was then taken to the Metallurgical Engineering Department's materials laboratory and sectioned to determine quality of the poured cast iron. Figure 2 shows the resulting microstructure of the cast parts from each team. The students, in the final report, had to use the information generated from the micorgraphs and discuss how the cast iron quality affected the design and any subsequent manufacturing processes. The rationale was to reinforce to the students that the amount of spheroidal or compacted graphite in the casting plays an important role both in final properties and machining operations. One group had excellent success and produced an iron with good nodularity which yielded the desired strength and machinability. The second group, on the other hand, had a considerable amount of compacted graphite in their casting which considerably altered the machining characteristics. In both cases, the iron matrix was predominantly ferritic.

Besides the cast iron, other materials had to be selected to complement the cast member. Criteria and concerns in selecting these materials were outlined during the course. These concerns ranged from the compatibility of dissimilar materials that might be in contact during use, up to and including environmental considerations that might affect the surface finish or lubrication needs.

A final aspect of material selection, not normally stressed in the engineering curriculum, is the use of vendor catalogs to select off-the-shelf parts or

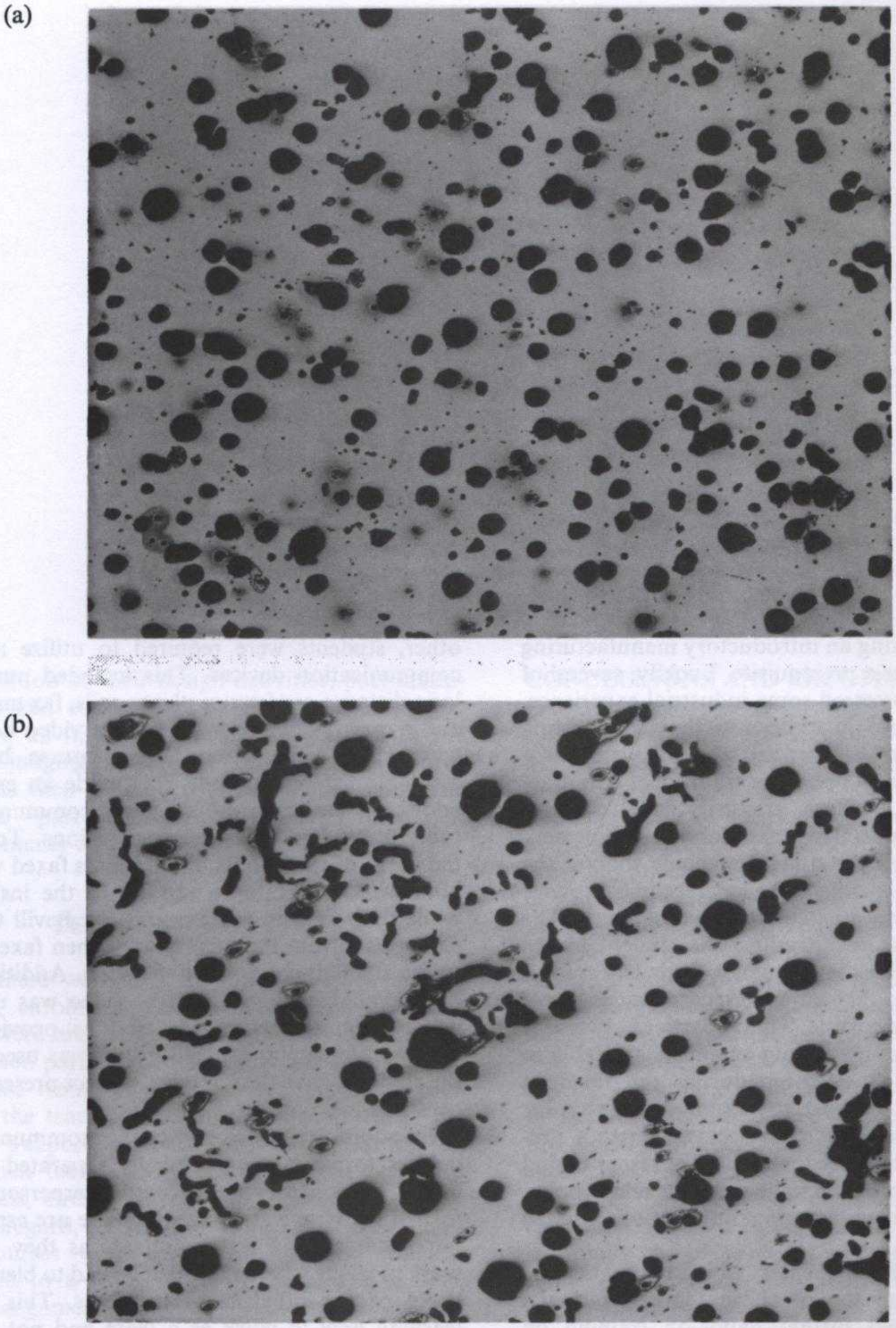

Fig. 2. (a) The graphite form in the casting produced by student group A. Excellent graphite nodularity is evident. (High percentage of graphite spheroids is present.) (b) The graphite form in the casting produced by student group B. Some degenerate (non-spheroidal) graphite is present. Unetched, x100.

components. This allows the engineer to avoid re-engineering parts that already exist and are commercially available. Often engineers overlook this simple concept and will design a 'special' part that could have been procured much quicker at a significantly reduced price. This concept was stressed throughout their project: don't reinvent the wheel if you can purchase it cheaper and quicker. However, if parts are purchased they must arrive on schedule, at the desired cost, and meet the required quality standards. Consequently, part of the emphasis was to require the students to ensure that the delivery date was acceptable and stay involved until the correct part arrived.

Manufacturing processes

Perhaps the most difficult topic to cover during the first offering was manufacturing processes. This was due to none of the students having had a formal manufacturing processes class. This experi-

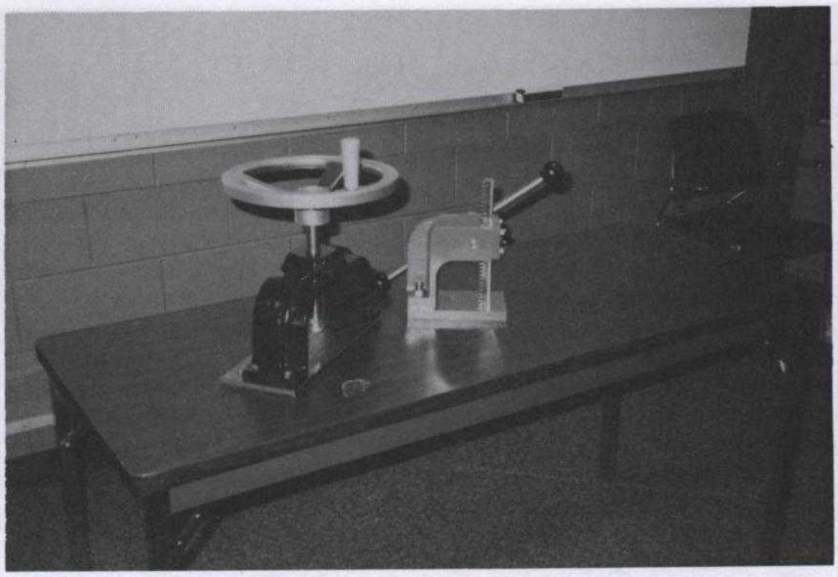

Fig. 3. Final mechanical presses as produced by student groups.

ence led to making an introductory manufacturing processes course a prerequisite. Luckily, several of the students possessed some industrial experience. During this phase, in addition to the metal-casting aspects described earlier, the students were introduced to machines used in a traditional manufacturing shop, i.e. those primarily involved with cutting operations. This material was supplemented with tours of the student machine shop at the University of Alabama and a local technical college which had a more extensive machine shop. The main intent was to introduce the student to the concept of machine terminology, feeds and speeds, and the need to rely on experienced tradespeople when they are available. This is particularly true if there are no manufacturing engineers available to assist the design engineer during the up-front portion of the concurrent design process. After making a manufacturing processes course a prerequisite, this topic became more a refresher period and allowed more time to be spent on other topics, in particular manufacturing implications on the product design.

Once at the Bevill Center, where the machining and assembly of the parts was carried out, the students received further hands-on training on both automated and manual machine operations. While there, they tested their new skills with simple tasks; however, they did not personally machine any of their designed parts. They co-ordinated with shop personel at the Bevill Center to fabricate and machine the parts and casting as per final dimensioned drawings.

Modern communication skills

The course was structured so that the students conducted a portion of the class at the university and the balance at the Bevill Center, located approximately 125 miles away. In order to convey information from one location to the other, students were required to utilize modern communication devices. This included numerous long-distance conference phone calls, fax machines and e-mail. A two-way interactive video hook-up was not operational for the first course, but was available for the second. This made an excellent addition, emphasizing modern communication tools utilized in real design situations. To effect the usage of these tools, the students faxed various homework and interim reports to the instructor while they were in residence at the Bevill Center. Comments from the faculty were then faxed back to the students for corrective action. Additionally, once available, the interactive video was used to deliver remote lectures as well as providing a video-conferencing capability that was used when the students gave their interim project presentation over this medium.

In addition to using modern communication devices to assist geographically separated design teams, the students had to learn interpersonal and formal communication skills. These are especially important skills for the students as they had to work in teams where their talents had to blend with those of the other team members. This meant learning how to work as a team and not just as individuals. An additional interpersonal aspect they learned was to interface appropriately with skilled tradespeople as well as communicate with engineering sales staffs at the various vendors. Communication on such diverse levels requires different interpersonal skills than those required for working with team members.

Equally as important is the ability to give formal presentations, not only to internal management, but also to customers. A well-prepared presentation is often the difference between a project that is declined and one that is funded. It can also provide follow-on opportunities. Thus, a final requirement for completing the course was to give a formal

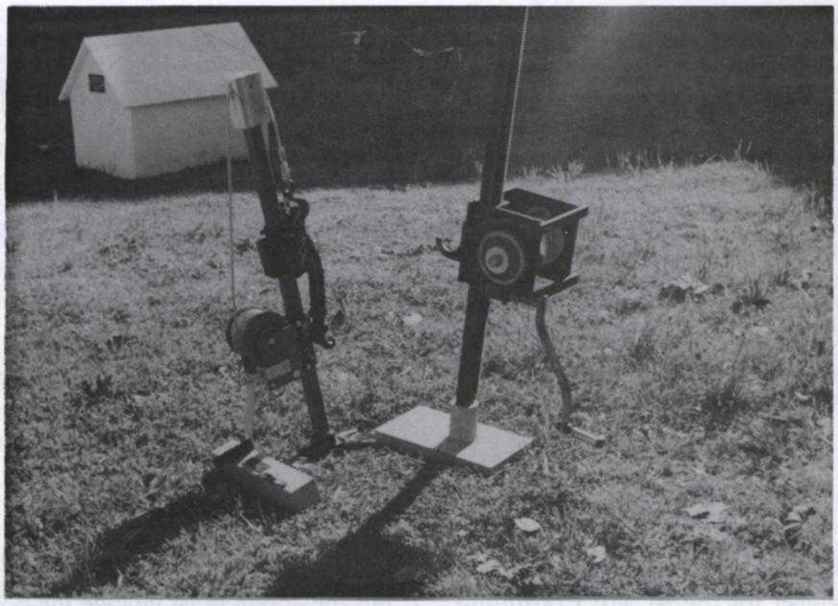

Fig. 4. Final jack-winches as produced by student groups.

presentation of their design activities, part manufacture and cost analysis. The presentation was open to all interested parties in addition to the faculty judging the student performance. The project was then deemed completed only when the finished part successfully passed functional requirements testing.

TEAM ORGANIZATION

As these were first attempts to teach such a course, enrolment was restricted. The first time there were six students and the second offering had seven participants. The students were divided into two teams of three or four members each where the team composition was dictated by the faculty's expectation of the skills needed. It was felt that each team needed members well versed in materials, stress analysis and mechanism design. In this regard, student grades from these prerequisite courses were compared and the students assigned to a team based on those grades. The team assignment was based on each team having at least one member strong in each area. However, it was left to the individual teams to determine which person was best suited to a given skill. Similarly, each team elected the person they felt would be best suited to act as project leader. Traditionally, the project leader is selected by the company based on past performance, but it is not inconceivable that in the future design teams will be formed and will select their own leaders.

CONCLUSIONS AND RECOMMENDATIONS

The modern product realization course has now been successfully taught twice. The three stated objectives were met in a new and unique manner utilizing many of the state's resources. The students were introduced to manufacturing issues and how they affect product design and the inportance of considering these issues in the very first stages of the problem definition. They also experienced the integration of the different engineering skills needed to aid the concurrent engineering process and to develop needed communication skills. More importantly, this was accomplished in an intensive 5-week period where success was dictated by having a working prototype that was designed, fabricated, and tested. We conveniently refer to this modern product realization as a 'start-to-part' experience.

During the second offering the students experienced first hand what happens when a bad concept is initially chosen. The design team attempted to tinker with the concept and make it work, just as is often done in industry. However, there was no way the concept could be manipulated to achieve the stated goal. In the end, the team had to retreat and develop a new concept and then produce the prototype in only half the available time. The end result on the prototype's quality and performance were noticeable. The success of the course's goals are demonstrated below. Photographs of the finished parts are shown in Fig. 3 for the mechanical press and Fig. 4 for the jack-winch.

REFERENCES

1. Improving engineering design: designing for a competitive advantage, National Research Council Report, National Academy Press, Washington, DC (1991).

2. J. R. Dixon, *Design Engineering*, McGraw-Hill, New York (1966).
3. A. J. Medland, *The Computer Based Design Process*, Chapman and Hall, London (1992).
4. J. E. Shigley and C. R. Mischke, *Mechanical Engineering Design*, McGraw-Hill, New York (1989).
5. A. Solomon, Innovating with teams and top-notch software, *Machine Design*, February (1994).
6. J. R. Dixon, The state of education, *Mech. Engng*, **113**, no. 2 (1991).
7. J. R. Dixon, New goals for engineering education, *Mech. Engng*, **113**, no. 3, (1991).
8. DARPA initiative in concurrent engineering, *Mech. Engng*, **114**, no. 4 (1992).
9. *Proceedings of Manufacturing International '92*, American Society of Mechanical Engineers, New York (1992).
10. Stanford integrated manufacturing association Ph.D. program, *Mech. Engng*, **114**, no. 10 (1992).
11. The master of engineering in manufacturing, *Mech. Engng*, **116**, no. 1 (1994).
12. J. R. Dixon and C. Poli, *Engineering Design and Design for Manufacturing*, Field Stone (1995).
13. D. E. Whitney, Manufacturing by design, *Harvard Business Rev.*, July–August (1988).
14. Eight steps to simulataneous engineering, *Manufact. Engng*, November (1992).
15. E. Crossley, A systematic approach to creative design, *Machine Des.*, May (1980).
16. M. F. Brereton, L. J. Leiffer, J. Greeno, J. Lewis and C. Linde, An exploration of engineering learning, *Trans. ASME Design Theory Method.*, **DE53** (1993).

APPENDIX

Specialty press problem definition

You are an engineer for the ACME Consulting Engineering Company. As such you have been selected as part of the design team for a project the company accepted from Widget Works.

Widget Works is a company that manufactures precision equipment on a moderate scale of production. They are well known for their manufacturing expertise but do not employ a large engineering staff, so all design is contracted out. Widget Works, through their network of contacts, has decided there is a niche market for a specialty press and management has decided to expend its own funds to develop this press. Management at Widget Works feels that the market will purchase 1000 presses a month at $299.99 each if development can be completed in a timely manner and the production costs held below $175.00.

In order to capture the anticipated market, Widget Works needs a working prototype with complete manufacturing plans in the next 3 weeks. Management at ACME realize the only way to accomplish this task in such a short timeframe is to develop a concurrent engineering design team that will practice the concept of modern product realization. You and two others have been selected for this team and it is your responsibility to develop, produce and test a prototype press, and specify the manufacturing plans. As of this time, this does not include performing a cost analysis of the per unit production price.

The minimum requirements for this press are:

Load capacity ___ Newtons
Press stroke ___ cm
Head deflection ___ mm

Widget Works has an excellent foundry capability and wishes to use the foundry as well as their automated manufacturing machines in this job. Therefore, they wish to cast the structural arm of the press as they feel this will be the most economic way to form the main unit of the press. Other parts may be ordered off-the-shelf, if cost competitive, or made in the shop. The prototype press is expected to be used initially in a manually operated mode, but the design must include the possibility for easy conversion to pneumatic operation at a later time when automated operations are envisioned.

Jack-winch problem statement

Mom & Pop's (M&P) Manufacturing Shop is a full service operation located in Vance. The shop is one of the two most complete in the area, i.e. the company has manufacturing personnel and equipment to handle moderately sized production runs. However, they do not specialize in prototype development. The company employs manufacturing engineers and skilled tradespeople, a large machine shop supporting both manual and computer operations, welding facilities, a foundry, and some computer-aided engineering tools.

Mercedes-Benz (MB) has contacted M&P about bidding on a project to rapidly design and build a prototype jack-winch device to be marketed as an option for their new All Activity Vehicle to be built in Vance. (They must have a working prototype and a production scale manufacturing plan in 5 weeks. If MB is happy with the prototype and production plan, they will negotiate with M&P to be the sole supplier.) As the basic vehicle design is still a closely guarded secret, the only information MB will provide is that the vehicle has about the same size and weight as comparable sports utility vehicles, i.e. Chevy Blazer or Ford Explorer. The device must be capable of lifting the vehicle for tire changes when needed, plus having the option of providing winch capabilities so the vehicle can be extracated from adverse situations that might occur.

MB will give no functional requirements except that the device must:

- be fail safe (locks in place);
- have a designed weak link (for easy repair upon failure) that has a safety factor of at least two backed up by analysis that will withstand litigation;
- be easily stowable in a 'small' volume;

- be relatively inexpensive;
- be 'lightweight' (remember women might have to use it); and
- be able to winch the vehicle at least 50 ft.

The management at M&P's realize the only way to achieve the goal in such a short time is to implement a concurrent engineering team that utilizes all available resources to supplement their capabilities. This includes the Bevill Center for Advanced Manufacturing Technology and the Metals Casting Technology Center. Management desires to use off-the-shelf items, standard stock material and sand castings in the project. The selected concurrent engineering team, of which you are a member, has been formed of people from M&P's the Bevill Center and the Casting Center. It is your team's responsibility to design, develop, produce and test a working prototype in this time period. Furthermore, MB wants manufacturing plans specified for full scale production of the device. Anticipated volume is 15,000 the first year, rising to 50,000 per year within 2 years. If M&P chooses to negotiate for the production run, an economic payback within 2 years of maximum production is desired. A description of M&P capabilities and cost structure will follow as will MBs marketing and pricing information. MB anticipates charging $60 for the option and this assumes a 100% markup on their part.

Dr G. L. Ferguson is a licensed PE. He received his BS, MS and Ph.D. degrees in mechanical engineering from New Mexico State University. Prior to becoming an educator, he spent over 16 years as a practicing engineer, developing, designing, fabricating and testing prototype research and development, test and evaluation fixtures for the defense sector. Dr Ferguson has drawn upon his extensive knowledge of design and manufacturing in developing this course. At present, Dr Ferguson is performing work using teams of graduate and undergraduate multidisciplinary students in manufacturing process and conceptual design initiation studies.

Dr J. T. Berry is broadly experienced in materials selection and manufacturing-related activities. He received the B.Sc. (Honours) and Ph.D. degrees in metallurgy from the University of Birmingham, England. His industrial and research experience includes periods with the Production Engineering Research Association, the Naval Construction Research Establishment, the Skefko Ball Bearing Company in the UK, and Climax Molybdenum Company and IIT Research Institute in the USA. He has occupied professorial posts in several US universities and recently moved from Alabama to become the first recipient of the E. P. Coleman Professorship of Mechanical Engineering at Mississippi State University.