Session 1625

Integrating the Product Realization Process (PRP) Into the Design Curriculum

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Abstract

For nearly the decade, team projects have been implemented in design related project courses. Although many of these courses are "capstone" type courses, some may be laboratory project courses linked with more traditional design courses. Certain elements remain common to team projects independent of the venue. The purpose of this paper is to outline the major items that are addressed as part of the implementation of projects associated with the product realization process (PRP). The paper will address the following major issues:

1. Acquiring projects that have a basis in industry. The relationship with the Design and Manufacturing Clinic at the University of Dayton will be explored.

2. The process of forming teams will be presented. Issues taken into account in this formation include individual interests and leadership styles.

3. The concept of the "Product Realization Process" forms the guidelines within which the teams perform. The major elements of this include defining the product needs, establishing specifications, developing conceptual designs, performing the final design and writing the final report.

4. Communication with the faculty and industrial mentors is essential. Informal methods of communication will be explored as well as the more formal oral and written reports.

5. Because there are many individual and team assignments the development of a grading system has become complex. Formal grading by the faculty mentors and evaluation by students of members of the team will be presented.

6. Assessment by industry mentors has been positive. An overview of the areas considered being strengths as well as areas for improvement will be explored.

A summary will be provided that correlates activities of these team related projects with assessment. Assessment will be related to ABET Criteria 2000.

I. Introduction

Traditional design practices have been replaced in "World Class Companies" by concurrent engineering, which also emphasizes the team approach to the design and manufacturing functions. Different organizations have different names for the process. One which has seemed to come to the forefront is the "Product Realization Process" (PRP) and is defined as "The process by which new and improved products are conceived, designed, produced, brought to market and supported. The process includes determining customer's needs, translating these needs into engineering specifications, designing the product as well as its production and support processes, and operating those processes." (1)

The elements of PRP can be classified as:

Definition of **customer needs** and product performance requirements
Planning for **product evolution**
Planning for **design and manufacturing**
Product **design/development**
Manufacturing process design
Delivery Process Design
Production
Customer services and support
Withdrawal (Product obsolescence)

Manufacturing managers and leaders have identified approaches and characteristics of the PRP as implemented in their companies.

Teams - Concurrent engineering/design teams are essential. The teams should be multi-disciplined with representatives from marketing, industrial engineering, industrial design, mechanical design, manufacturing and purchasing. Members of the team should be active participants from initiation to product obsolescence.

Commitment - The mental attitude of the teams must be correct; team members must believe that the success of the team is important for quality and survivability of the company!

Quality - Is perfection important? Team members should believe that perfect performance is possible on all levels. Continuous improvement must occur until you reach perfection.

Customer - The driving force behind product design is customer needs and product performance requirements

Manufacturing - Manufacturing for design is not design for manufacturing. What can be done in manufacturing to support the design process? Design, development and manufacturing are good areas to interchange people on a periodic basis.

Design for Manufacturing and Assembly - A good design is a simple design. As stated by Dewhurst (2) "Good design is like good writing; perfection is reached not when there is no more to add but when there is no more to take away". Good design characteristics include simplicity; manufacturability; ease of assembly; flexibility for later changes; ease of disassembly; ease of use.

Communication - The requirement for effective communication permeates the entire process. There should be open and honest communication among all members of the team. Everyone on the team should be charged with the responsibility of asking questions. Real people from many different backgrounds bring many points of view. The design process should be documented.

II. The Project – An Overview

The project that the (student) team is to complete is decided the first week of class and is selected from a list of projects provided by the Design and Manufacturing Clinic.(3) The general criteria is that it must be a mechanical system that includes machines powered by an electric motor and uses torque transmitting elements to perform some useful function. Pneumatic and hydraulic systems may also be a good approach for some support systems.

Students will be involved with the selection of the project based on overviews provided the first week of class. Students are asked to identify the projects that are of interest to them. The instructors form teams based on several factors, including interests of the members of the class. Once the teams are formed there is additional flexibility regarding the project and scope that may be further defined by the team and the sponsors.

The organization of the team is up to its members. Some teams decide to have a formal team leader while most let the team take on natural leaders. The allocation of work is also up to the team of members. Team members are asked to evaluate the team effectiveness three times during the term. Greater weight is placed on the last evaluations.

Technical and design related subjects are sometimes discussed during some labs. Initially, the design process is described in detail. Various types of hardware and mechanisms are presented early in the course to provide a basis on which to make future technical decisions.

Time is allocated during nearly every lab period to allow teams to conduct team meetings. The instructor(s) are available during these class meetings to answer both technical and procedural questions. These team meetings are used for design decisions and team scheduling. The intent is to help students to organize the team function but not intended to be the only time the team meets.

After the conceptual designs are generated a decision analysis is performed. The team meets with the instructor who will act as a supervisor or mentor on the project. At this time it will be determined if the project is possible and if there is enough substance to provide a challenging mechanical design. The merits for each design and the reason for the final decisions are articulated.

The instructor performs the role similar to a manager or supervisor in industry. The work has been delegated while the supervisor follows the progress of the project and offers advice as needed. There is not a target or a correct answer to design problems and projects. When major decisions need to be made regarding the direction for the project every attempt is made to have the entire team present. As a minimum, at least two members need to be present. To maintain efficiency, if a technical problem needs to be solved, those working on the problem should seek advice together.

The product realization process has been described in many different ways. (4) The major issues as it relates to the design course are shown in Figure 1.

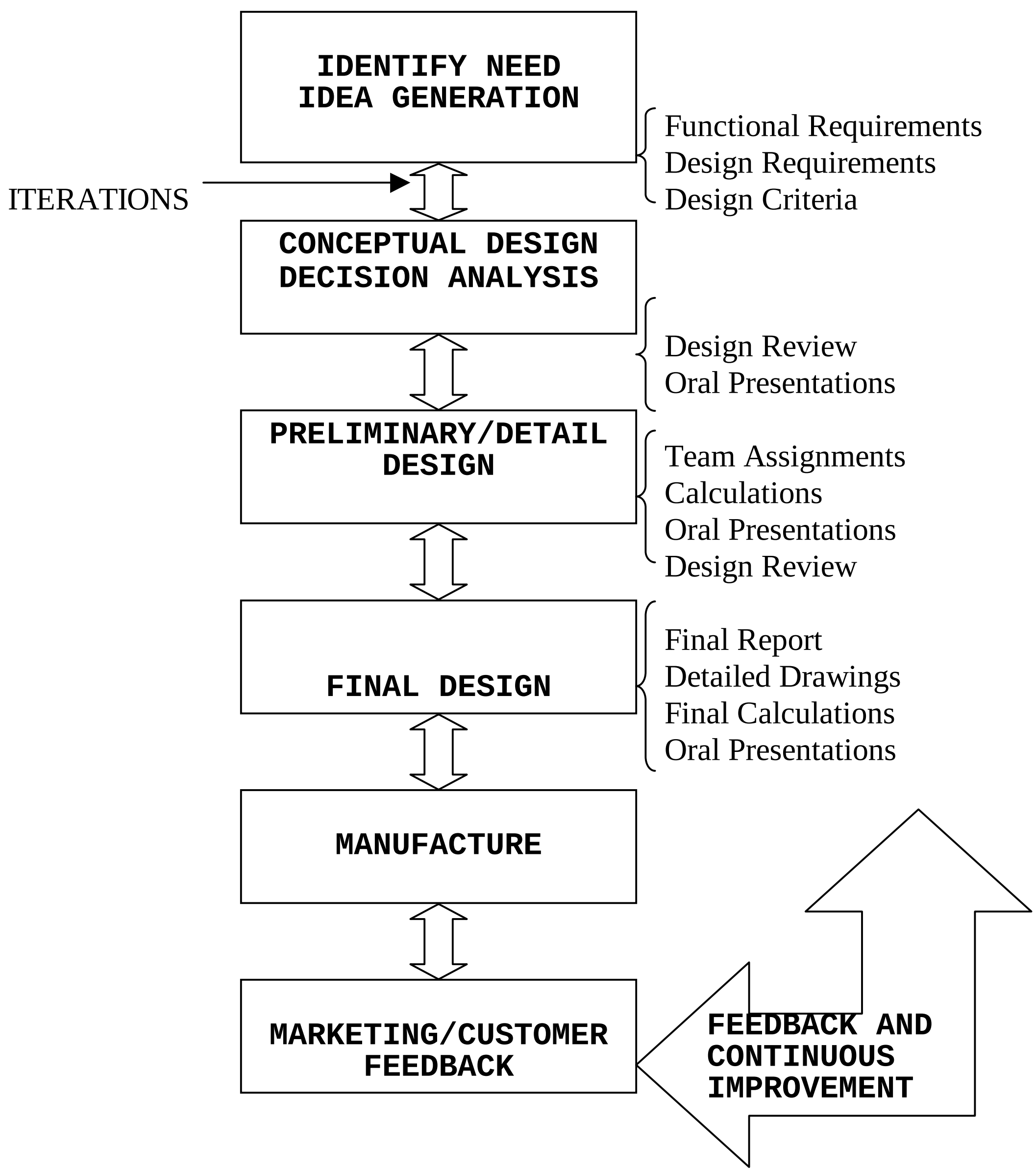

Figure 1. The Product Realization Process in a Design Course

III. Establishing Need and Generating Ideas

Every design or redesign action takes place because a need exists and has been identified. Some needs are not based on commercial product development and/or making a profit but to benefit humanity. Physically or mentally challenged people have a need for mechanical devices to assist them in leading as near to normal lives as possible. In many of these cases we are not seeking a profit for the customer but to help individuals in need.

Once a need exists the specifications for the device must be defined. Some look at these specifications in three categories: functional requirements, design requirements and design criteria. (5)

Functional requirements are those specifications that identify WHAT the design is required to do. For instance it has been determined that there is a need for a mechanism that will transport a backpack from the back of a wheelchair to the front for access by the occupant then a functional requirement would identify this. Note that the "how" is not identified here. A typical functional requirement might be "Design and develop a mechanism that will move a backpack from the back of a wheelchair to the front and return it to the back at the command of the wheelchair occupant. This must be done by a power source other than the occupant." Overall, the functional requirement is a general statement of what the device is to do.

The design requirements specify how it is to be done and the values of some of the constraints. Several design requirements for a backpack mover might include "Must be able to move a backpack that weighs 40 pounds and has dimensions of 14 inches wide 12 inches deep and 22 inches high" and "Must utilize the electrical battery attached to power wheel chairs as a source for powering the mechanism". However, it should be noted that the exact design of the mechanism has not been specified. This is left for a later phase that addresses the conceptual designs.

The design criteria address the "guidelines" within which the design must conform. These are addressed by Pugh (6) in his book on Total Design as elements of the product development process within the design boundary. Typical issues that are addressed include safety, cost of the system, ergonomics, aesthetics, materials, performance, size, manufacturability, and others. It is important that these terms be mentioned and that the relationship to the design be articulated. The most important criteria is safety. It is not sufficient to just state that safety is important but to identify the safety issues that must be addressed.

The first actions that must be taken by an individual in this phase are:

develop the functional requirements,
design requirements and

design criteria
define the deliverables

This is done on an individual basis first and then will be further developed in the team.

Conceptual Design

The conceptual design process is the most critical part of the process. Several sources have documented the importance of the conceptual design phase. (1,2,4) Here it is shown that the greatest flexibility and the lowest cost for design changes are early in the process. Thus it is imperative that this phase be taken seriously and with as much information as possible. It is critical to know what the customer wants. It is important to have a good knowledge of the mechanical devices that might facilitate the design.

The concepts are based on the students' individual knowledge of mechanisms as well as their being able to take risks and come up with some off-the-wall ideas. Members use ingenuity and initiative that may trigger some ideas in the minds of others on the team.

Each member of the team is required to generate concepts independently from the other members of the group. Each member will generate three concepts for the design. Thus if there is a group of 4 persons the group should have 12 conceptual designs. Since there may be similar ideas it is possible that a few of the designs will overlap. Ideas from one individual should be significantly different. In other words, it is not acceptable for a person to have the same design for all three concepts and only change the location of the motor or switch a pulley system with a chain and sprocket from one design to the next.

The format of the conceptual is a sketch and narrative on green engineering paper and in sufficient detail to identify HOW it will be done and with what kind of mechanism. The conceptual design should specify in some detail HOW the design will meet the intended requirements and criteria.

When the conceptual designs have been developed each individual will perform a decision analysis of their concepts. The criteria on which the decision for each concept will be based is the design requirements and design criteria developed earlier. The application of this along with the weighting procedures are defined during class and utilize a form similar to that shown in Figure 2. (7)

With the concepts and the decision analysis each individual will interact with the team to present his/her findings. The team will then synthesize the designs into four team concepts and develop a decision analysis on which to select the top candidates.

After the team has reached some conclusions, presentations will be made to the class and/or sponsor to inform them of the results of the conceptual design phase. The outline for the oral presentation is outlined in class.

In summary, the needs and idea generation phase requires that each individual generate at least three concepts of how the objectives can be accomplished. This is followed by individual and team decision analyses. The phase is concluded with an oral presentation that articulates the individual and team decisions. The team concludes this phase by developing a schedule (Gantt Chart) for the remainder of the term. (Figure 3.)

Preliminary/Detailed Design

With the conclusion of the conceptual design phase it is now time to "solidify" the design so that a concept is agreed upon and forms the basis for future analysis and the final design. Everything that was considered as part of the conceptual design phase is now focused on one design. This one design could be one of the original conceptual designs or a "hybrid" of several designs. Input from the sponsor should weigh heavily on your decisions.

The detailed design is the design that now approaches the configuration that will become the final design. The materials to be used in the design as well as its geometry are more clearly defined. It is at this point where questions can now be answered regarding the availability of parts from vendors or should they be fabricated. Some rough calculations are made to determine if the conceptual design is feasible.

A drawing of the "detailed design" must be generated. This drawing should approach an engineering drawing but is not required to have dimensions. The purpose of this drawing is to itemize the parts that will be required in the final design and to determine which engineering calculations will need to be performed. Thus, in conjunction with this detailed drawing it will be necessary to develop a parts list and reference the parts to the drawing.

With the development of the drawing and the parts list it is up to the team to decide the analysis and calculation assignments within the team. Each member of the team is required to perform engineering related calculations. A concept that has worked well in industry is the concept of "two to do one". Although this is not always feasible it allows team members to do an analysis and compare their approach and calculations with others in the group. When significant differences exist a more detailed analysis is required.

At this stage, the action items for individuals and the team are to provide:

A detailed drawing of your concept (without dimensions and sizes)
A parts list of for the detailed design
An updated and complete decision analysis
A listing of assignments and analyses to be performed within the team
An updated schedule, sometimes referred to as a Gantt Chart

The above five items are submitted to the sponsor and instructor in the form of a letter report. An oral presentation that concentrates on the details of the design and the steps to the final report is given. This presentation is made as a part of lab time at the University with the mentors from the sponsor invited to the presentation. The total presentation will be 20 minutes or less and should cover new material NOT a rerun of the conceptual design presentation. An example of a Gantt Chart is shown in Figure 3 for a simulated project. It also shows the major phases and milestones for the project.

Figure 2. Decision Analysis Chart

CRITERIA	WEIGHT	CONCEPTUAL DESIGNS (PROPOSED CONCEPTS)							
		Concept A		Concept B		Concept C		Concept D	
		R	V	R	V	R	V	R	V
1.									
2.									
3.									
4.									
5.									
6.									
7.									
8.									
9.									
10.									
TOTAL		Sum		Sum		Sum		Sum	

W = Weight – Indicates the relative importance of the criteria
R = Rating – Indicates the performance of a given concept with respect to each criterion.
V = Value – The product of the weight (W) times the Rating (R).

Figure 3. Gantt Chart and PRP Schedule

	SCHEDULE			
Activity	**Month 1**	**Month 2**	**Month 3**	**Month 4**
Establish Need Select Project Functional Req. (1) Design Req. (1) Design Criteria (1) Identify Deliv. (1)				
Conceptual Design Dev. Ind. Concept (1) Team Req. & Crit. (2) Ind. Decision Anl. (1) Team Decision Anl (2) Oral Presentation (2) Dev. Gantt Chart (2) Submit Designs (2)				
Detail/Prelim. Design Evaluate Sponsor Feedback Revise Team Dec. Anl. Determine Feasibility Initial Calculations (1) Develop 3 View Draw. Develop Parts List (2) Identify Req. Calcs (2) Submit Detailed Des(2) Oral Presentation (2)				
Final Design Select Components Design Components(1) Perform Analysis(1) Cost Estimate (2) Engineering Dwgs (2) Write Narrative (2) Assemble and Submit Final Report (2) Final Oral Pres. (2)				

V. Final Design

Having completed the conceptual and detailed design phases, the overall geometry of the design (without actual dimensions and parts) is now complete. It is time to finalize the design with respect to specific parts and dimensions. The most efficient method for conducting this phase is to discuss in team meetings what needs to be done and who is going to do it – then just do it! It should be understood that individuals and not teams make accomplishments. Team communication is important but team members complete the actual work. Everyone must take responsibility for the quality and completeness of the final design.

This task is what many considered to be engineering design in the past. It is in this task that the calculations are performed. Up until now very little has been done in the way of design calculations. It is here that the final details of the design are analyzed and developed. Calculations include stress analysis (including shear and moment diagrams), design of machine components like gears, springs, shafts, welds and the integration of electrical components like motors and controls.

It is required that a set of engineering drawings be developed that can be used by the sponsor to fabricate the design. It is also possible that the design could be built in a future class within the curriculum. The assembly drawing should be a CAD generated drawing no less than a D size. Individual component drawings should also be generated.

The project report is to be accompanied by a detailed narrative of the design and the major items and issues incorporated into the design. The results of the project will be documented orally in a final 45-minute presentation to the sponsor and the class.

VI. The Final Report

Over half of the grade in this course is based on the final project. The team effort will represent 45% and 10% will be on individual work on the final design. The organization of the final report follows.

The report narrative is contained in the front of the report and provides a background of the project. This should include the "need" as defined as well as the functional requirements, design requirements and the design criteria. The design is described in terms of how it fits into the "big picture" of the overall process.

The conceptual design and decision analysis process is outlined. What are the advantages of the design? What are the outstanding features of the design that became the final design?   Is anything unique about your deign? Should anything be submitted for a patent? Much of the discussion will require that figures be provided of the designs and integrate them into the text. A narrative by itself will not work.

The conclusions address how design meets the design criteria and the design requirements. Did anything need to be sacrificed? Is this a reliable design? Is it safe? Can it be built? Did the effort remain on schedule during and after the effort?

The recommendations focus on what would be done different if the team would start over? What would be recommended to the people that will build this design? What is the procedure to maintain and operate the design? Have operating instructions been developed?

A cost estimate is included, which analyzes material cost, the cost of labor and overhead. The cost per unit for various quantities is detailed.

Design calculations are performed on green engineering paper and include the part name, number (as referenced to the assembly drawing), the name of the person making the calculation and the page number. A brief narrative is incorporated into the calculations, especially if assumptions are made. Overall it should be clear which part is being analyzed, the assumptions that are made and the final result. Neatness and ease of understanding are taken into account.

References used for calculations are listed, copy of the pages of any catalogs that are used to select and calculate dimensions are included. Calculations verify the adequacy of purchased parts.

The calculations should show that the part is safe and that it will perform its intended functions.

VII. The Oral Presentation

Each group provides a final oral presentation. The presentation will include the following:

1. Introduction - overall descriptions of the design.

2. Detailed description of a part of the design and summary of the calculation (each member of the group must participate in the presentation).

3. What is the status of the design project at this time? What remains to be finished?

4. Conclusions. Were the goals achieved?

5. Recommendations. What would you do differently? What do you recommend to those who will manufacture this machine?

VIII. Grading

Perhaps one of the most difficult issues associated with team projects is the allocation of individual grades. Some believe that one grade should be given based on total team performance. Since the course is modeled to reflect industry practices, the philosophy of grade allocation also follows industry performance practices. Salary distributions are based on performance and appraisals of individuals and not on total "team" performance. Thus, some grades are individual grades and others are team grades. Individual grades are given for development of the specifications, conceptual designs and individual file folders.

Figure 4. Project Grades for Term

	From	Person 1 murphy	Person 2 jones	Person 3 smith	Person 4 einstein
Evaluation1	Person 1	22.00	48.00	36.00	47.00
	Person 2	41.00	22.00	32.00	41.00
Conceptual	Person 3	49.00	49.00	24.00	47.00
	Person 4	39.00	40.00	25.00	23.00
Total		151.00	159.00	117.00	158.00
Evaluation 2	Person 1	24.00	49.00	34.00	49.00
	Person 2	40.00	20.00	31.00	40.00
Prelimin	Person 3	50.00	50.00	23.00	50.00
	Person 4	38.00	38.00	24.00	19.00
Total		304.00	314.00	224.00	316.00
Evaluation 3	Person 1	25.00	49.00	35.00	50.00
	Person 2	49.00	25.00	45.00	50.00
Final	Person 3	48.00	48.00	23.00	49.00
	Person 4	48.00	48.00	32.00	23.00
Total		680.00	680.00	540.00	688.00
Sum 3 Evaluat		1135.00	1153.00	881.00	1162.00
Sum of all Eval =		4331.00			
grades/sum		0.26	0.27	0.20	0.27
No. Stu. =	4.00	1.05	1.06	0.81	1.07
Project Possible	400.00				
Grade Actual	340.00	356.41	362.06	276.65	364.89
Individual Folder	100.00	90.00	90.00	85.00	95.00
Proj. Total=		446.41	452.06	361.65	459.89
Oral 1 =	50.00	45.00	44.00	43.00	48.00
Oral 2 =	50.00	43.00	42.00	40.00	48.00

Oral 3=	100.00	80.00	85.00	75.00	93.00
Conceptual =	150.00	120.00	125.00	115.00	140.00
Preliminary =	50.00	45.00	45.00	45.00	45.00
Homework =	100.00	90.00	87.00	85.00	98.00
Total Grade =		869.41	880.06	764.65	931.89

Individual grades are given for oral presentations, which are further subdivided into team and individual performances. For instance individual grades are given for visual aids and calculations, while team grades are given for team preparation and effective use of time.

The final report is graded as a team effort but modified based on the evaluations of team members of each other. After the conceptual design phase, members perform the first evaluation, and given a weight of one (1). After the detailed design phase another evaluation is performed with a weight of two (2). At the conclusion of the project the evaluation is given a weight of four (4). These are normalized and used as a multiplier with the final report grade. For example if the team received a grade on the report of 445 points out of a possible 500 an individual that receives a 1.07 from the evaluations would receive a report grade of 476. Another team member that did not receive as high of evaluations, say a 0.94, would receive a grade of 418 out of 500. Although this may seem complicated, it is easily implemented with a spreadsheet like that shown in Figure 4.

IX. Conclusions

The above described approach to the product realization process has evolved over the last 10-15 years. Although it is not perfect it has met the needs of the department and the students by providing a significant design experience that is reflective of that which would be encountered in industry. Through the assessment process it has been determined that the students are in agreement that they had a significant opportunity to apply the principles of design as part of their curriculum.

At the conclusion of the project the mentor(s) from the sponsoring industries are asked to fill out a survey for assessment purposes. It has been encouraging that in nearly all cases the sponsors have indicated that the student teams have met or exceeded the project goals and objectives. Furthermore, the mentors have indicated that the completeness of the final report and the final oral presentations meet or exceed the level that is expected of the engineers in their organization.

An area requiring further attention has to do with the interdisciplinary nature of the projects and the courses. In general the projects have been narrow in focus requiring only one discipline (Mechanical Engineering students OR Electrical Engineering Students). It has been reported that it would be desirable for projects to be interdisciplinary in nature to more nearly match the industrial situation. We are exploring this for future projects.

Many issues are related to ABET Criteria 2000. Issues covered in this class related to the new criteria (a-k) include:

1. The ability to APPLY knowledge of math, science and engineering
2. The ability to design a system, component or process to meet desired needs.
3. The ability to function on multidisciplinary teams.
4. An ability to solve engineering problems
5. An understanding of professional and ethical responsibility.
6. An ability to communicate effectively
7. An ability to use modern engineering tools for the practice of engineering.

X. References

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