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TEACHING INTERDISCIPLINARY DESIGN: ENGINEERING ASSISTIVE TECHNOLOGY

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Abstract. *Seeking for innovative approaches to expose students to concurrent interdisciplinary design in critical areas to society has lead to the collaboration between the School of Engineering and The Puerto Rico Assistive Technology Project at the Medical Sciences Campus of the University of Puerto Rico. The objective is to provide services that facilitate the integration, inclusion, independence and productivity of individuals with disabilities into the communities in which they live. To achieve these goals it is necessary to address areas as diverse as: health, education, engineering, psychology, rehabilitation and social work. Students participating in the Mechanical Engineering capstone design course are presented with a series of needs in the Assistive Technology Area. The students must study and select a need for which they will perform the full Research and Development cycle for a new product to satisfy the need. They must interact with professionals in all disciplines related to the project. The product's design is subject to market, cost, manufacturing and engineering constraints in addition to all ergonomic, aesthetic and functional requirements. An important component of the final report is a full working prototype for the new product. The paper presents the concurrent engineering process followed and various case studies.*

Keywords: *Concurrent Engineering, Assistive Technology, Education*

1. INTRODUCTION

The Mechanical Engineering "Capstone" Design Course, INME 4057 is designed to give the students an opportunity to experience scenarios typically encountered in local industry. Other courses in the curriculum which provide design experiences are the elective courses INME 5015 Special Topics, INME 5995 Special Projects with projects such as the Solar Powered Vehicle and the Formula SAE Vehicle (Serrano 1991), (Serrano 1994a), (Serrano 1994b) which provide a hands on, interdisciplinary and concurrent product development experience. These electives allow students to develop skills in the areas of organization, project management, budgets, communication and testing (maintenance and service which are very important product related issues). These skills are key to future entrepreneurs with engineering background. These projects continue to be very popular among the student body but unfortunately they have a limited number of spaces available, and require much effort, physical resources, large budgets and at least a full years commitment. Therefore many students graduate without experiencing "hands on" real world, interdisciplinary, concurrent design applications. One of the goals of the approach taken by the author in INME 4057 is to give the students an alternative venue to experience such product development scenarios in a much shorter period and using less resources. A collaborative effort between the Medical Sciences Campus and the School of Engineering provides such an opportunity.

The Puerto Rico Assistive Technology Project (PRATP) at the Medical Sciences Campus of the University of Puerto Rico has as a main objective to provide services that facilitate the integration, inclusion, independence and productivity of individuals with disabilities into the communities in which they live. In order to achieve these goals it is necessary to address areas as diverse as: health related professions, education, all engineering fields, psychology, rehabilitation and social work. PRATP has been able to identify several barriers that severely limit the access to Assistive Technology (AT) on the Island. Barriers such as: (i) high cost of AT devices, (2) Unavailability of funds and programs, (3) Scarcity of properly trained professionals to evaluate AT needs, and (4) Language barriers, have a negative impact in the development of AT devices.

AT devices may be classified in two broad areas: (1) Adaptations to meet special needs of individuals and (2) universal designs. Adaptations address problems encountered by individuals with physical disabilities in their daily activities in order to improve rehabilitation of individuals and provide liberty and independence at a low cost. Universal designs is a holistic approach to creating environments and products that are usable by many people regardless of their abilities and age. These make a significant contribution toward promoting the independence and inclusion of persons with disabilities in the mainstream of society. A third important area identified addresses recreational activities. Incorporating exercise into the lives of individuals with disabilities enables them to enjoy the physical and psychological benefits of fitness, achieve greater independence, and perform activities of daily living with less fatigue.

2. OBJECTIVES

The objectives of the collaborative effort are twofold: first to teach engineering design exposing students to the complete product design cycle in a concurrent and interdisciplinary setting, and second to provide a service to individuals with physical disabilities and special needs.

3. THE NATURE OF PRODUCT DESIGN

A general scheme for the Product Design Cycle is shown in Fig. 1. The dark arrows the path for the "ideal" Design Process. One of the best definitions for design is given by Woodson (1966): "***Design:*** *An iterative decision-making activity to produce the plans by which resources are converted, preferably optimally, into systems or devices to meet human needs"*. By nature it is an iterative process, therefore as shown in Figure 1, it may be necessary to return to previous stages as the design unfolds (indicated by paths with lighter arrows). A summary for each stage is presented in the next section.

Design Process

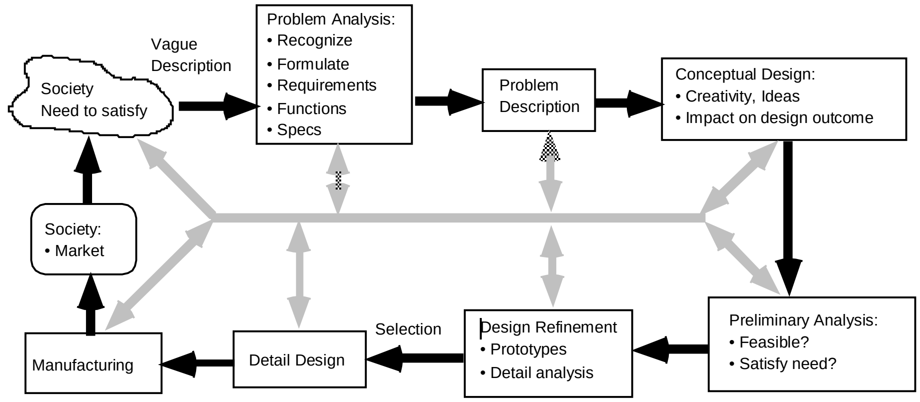

Figure 1 The Product Design Cycle

In concurrent or simultaneous engineering, teams composed of representatives of diverse engineering and management areas must see that the concerns (constraints) of their respective areas are taken into account at each stage of the product design. For example, it is no longer necessary to wait for manufacturing consideration to be brought into the product design as the final stage. This is also known as the Design for X approach, where X represents the various considerations. Much of the work in the product design is performed in parallel, therefore increasing the need for communication, coordination, negotiation and compromise. Some of the benefits of concurrent design are: (1) Reduces the Product Design Cycle (increases competitiveness), (2) Improves Design Quality, (3) Exposes all Costs, (4) Lowers manufacturing Costs, (5) Improves Communications, (6) Reduces Productions and Setup Times, (7) Reduces Part Count, (8) Increases Functional Capabilities and (9) Reduces Engineering Changes and Rework.

4. COURSE STRUCTURE

The course is structured to follow the product design cycle as close as possible. Progress reports and oral presentations are required at each stage. A brief description for each stage follows.

4.1 Problem Description

The first step in the design is to produce a formal Problem Description given the initial need. This requires a careful needs analysis due to the generally vague description of the need as initially presented to the team. The students must carefully formulate the problem in engineering terms such that the description will serve as a guide in the design process and as a "contract" with the client. They must spend time talking with professionals in related fields in order to identify the requirements, functions, specifications and constraints of the intended product.

4.2 Concept Generation

A number of concept generation strategies are discussed as part of the course. The main objective is to provide tools that stimulate the student's imagination in the generation of solutions to their particular design problem. The students must generate a total of fifteen concepts per person. That is 45 to 60 different ideas per team depending on the team size. The rationale for the apparent large number of required ideas is that the first five to ten ideas will generally represent obvious solutions. The last ideas are those which generally require a greater amount of effort and therefore will have a greater probability of yielding new, innovative and unexpected solutions. The basic strategies discussed in class are:

1) Search historical Information.
2) Inversion or change of mental frame.
3) Use of Analogy.
4) Brainstorming.
5) Morphologic Analysis (and Combinatorics).
6) Problem Decomposition.

Due to the scope of the paper these will not be described in detail, the interested reader may refer to the literature for further details: (French 1985), (Hubka & Eder 1988) and (Pahl & Beitz 1988).

4.3 Preliminary Design Evaluation

Three steps are required as part of the preliminary evaluation. First the 60 concepts must be reduced to the 15 most promising. This is accomplished using the Plus and Minus (+/-) Method. These are then further reduced to 3 finalists using the Weighting/Rating Method. An additional first order analysis is performed to select the final design concept to be developed. During this process new concepts may appear as a consequence of combining the best features of concepts that get eliminated. Each method is presented below.

Plus and Minus (+/-) Method. The method consists of selecting an arbitrary design as a basis (the Datum) and comparing all other concepts with the datum on grounds of the design criteria. When performing the comparison if a given criteria is considered to be better for the concept than for the datum it receives a "+" (represents +1) if it is considered to be worse it receives a "-" (represents -1). In the event that they are considered equal the score is "s" (represents 0). The result for each concept is the sum of the plus and minus scores. The top fifteen scores are considered for further evaluation.

Weighting/Rating Method. The method is similar to the Plus and Minus Method except that it allows for a more refined criteria evaluation. A weight (w_i) is assigned to each evaluation criteria (i) according to its importance in the overall design. The sum of the weights must be 100 ($\Sigma w_i = 100$). Then each design is evaluated using these criteria and a rating is assigned for each criteria in the range from 0 to 10 ($c_i \in [0 \;\; 10]$), where 10 is the best rating. The final score (s_i) for the i^{th} criteria is the multiplication of the rating and the corresponding weight ($s_i = c_i * w_i$). The final score for a design is then the sum of the scores it obtained for each criteria (Σs_i). Those designs resulting in the highest scores are selected for the preliminary design stage.

Preliminary Design Analysis. At these stage the top three finalists are taken an additional step where first order analysis is performed. For example: manufacturers for diverse components are located, costs are estimated, kinematic analysis/simulations performed and sketches of the product produced. This stage allows the student to have a more complete picture of the alternatives before they actually commit to the final design. The final selection is a result of a presentation to the "clients" (PRATP) in which the alternatives are presented and explained.

4.4 Design Refinement

Given the final selection the student team must perform a more rigorous engineering analysis including: detailed kinematics, dynamics, force analysis, stress analysis, component selection, part drawings and manufacturing process selection. Figure 2 shows an example Finite Element Analysis of a part performed at this stage. A product prototype is then constructed. During the construction of the prototype many considerations that may have been overlooked until this point surface and must be dealt with, sometimes requiring modifications to the design. The prototype is then presented to the "client" (PRATP) for feedback.

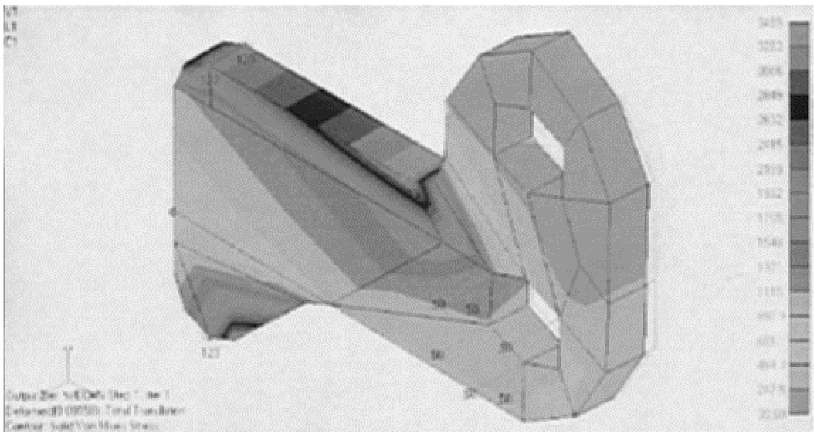

Figure 2 Sample Finite Element Analysis

4.5 Detailed Design

With the feedback obtained from the prototype the final drawings, parts list, assembly, manufacturing, cost, and operations documentation are generated. This information is part of the team's final report. The student team must prepare a final presentation describing the final design and demonstrate a functional prototype.

4.6 Manufacturing

Due to the scope of the course, manufacturing is limited to the prototype. The detailed design addresses most of the manufacturing considerations. It is also important to mention that most of the products in this area are required to have a low cost and it is desirable that it may be assembled by the end user's family.

5. CASE STUDIES

The approach has been in place for seven semesters. Typically twelve students are regestered in the course and four three-member teams are formed per term. Over 28 projects have been developed over this period of time. A sample of the projects developed include: (1) Power Wheel play vehicle for motion disabled children, (2) A Transfer Mechanism for Wheel Chairs, (3) A Bowling System for the Motion Disabled, (4) Standing Frames, (5) A Dual Use Wheel Chair, (6) Merry-go-Round, (7) Shower Helper, (8) Book Assistant, (9) Bicycle Adapters and (10) Wheelchair elevator among others. Of the above case studies the Power Wheel Adaption is presented as an example of an adaptation to meet the needs of an individual and the Transfer Mechanism as an example of a universal design.

5.1 Power Wheel Adaptation

The need addressed was to provide a means by which a child that has cerebral palsy could use a battery powered play vehicle. In addition, as a safety feature, the adult supervisor should be provided with an override safety measure. Low cost is an important requirement, a commercially available toy without the safety override costs over $3,500. It is intended that the design be an adaptation to an existing toy, preferably as a kit so that the parents may perform the adaptation themselves. Typical Gantt Chart for the project is given in Figure 3.

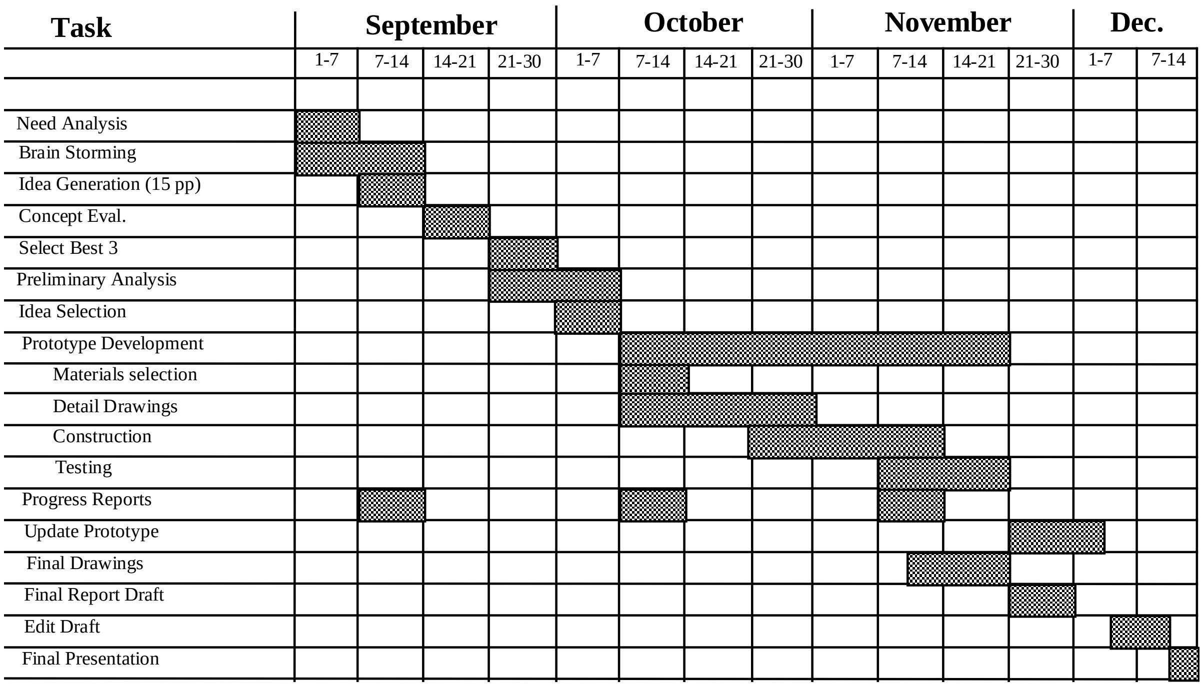

Figure 3 Typical Gantt Chart

The students generated over 60 different concepts using the concept generation techniques. The evaluation procedure required that the students reduce the 60 ideas to the "best" 15 using the +/- Method described in section 4.3. Then these were evaluated using the Weighting/RatingMethod to produce the three finalists. The criteria used were: Performance, Maintenance, Installation, Ergonomics, Cost, Reliability, Quality, Materials, Weight, Safety, Size/Space, and Instructions. The finalists were presented to the "clients" (PRATP) and discussed accordingly, therefore the students obtained additional feedback before committing the design. Table 1 shows a sample evaluation table. From the interaction the final concept was selected and a detailed design produced. A prototype was generated using the detailed design, specific details changed and evolved during the manufacturing process due to constraints which in some cases did not appear until this point in time. Figure 4 shows final design which is based on a differential in speed between the traction wheels to achieve steering. Small auxiliary wheels are placed under the front to minimize friction from the original front tires of the vehicle. The auxiliary wheels respond much like the shopping cart wheels.

Table1 Weighting/Rating Example

Criteria	Weight		#24			#25			#26			#27	
	(Wi)	Com	Score	Value	Com	Score	Value	Com	Score	Value	Com	Score	Value
Performance	15	adequate	6	90	good	7	105	good	7.5	112.5	good	7	105
Maintenance	6	low	7	42	low	7	42	low	7	42	low	7	42
Installation	4	hard	2.5	10	hard	2	8	hard	2	8	hard	2	8
Ergonomics	10	ave.	6	60	good	7.5	75	good	8	80	good	6	60
Cost	10	inexp.	9	90	inexp.	9	90	inexp.	8	80	inexp.	9	90
Reliability	10	high	8	80	high	8	80	high	8	80	high	8	80
Quality	10	high	7	70	high	8	80	high	8	80	high	8	80
Materials	6	next day	7	42	next day	8	48	next day	8	48	next day	8	48
Weight	2	2 lbs	8	16	2 lbs	8	16	< 2 lbs	8.5	17	2 lbs	8	16
Safety	15	high	8	120	high	8	120	high	7.5	112.5	high	8	120
Size/Space	10	v. good	9	90	v. good	9	90	v. good	9	90	v. good	9	90
Instructions	2	low	2	4	low	2	4	low	2	4	low	2	4
	100			714			758			754			743
Selected ideas							¦			¦			¦

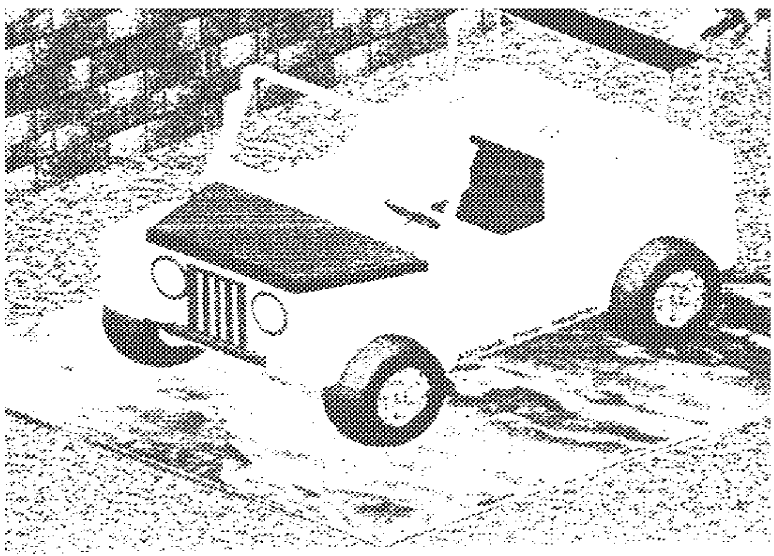

Figure 4 Final Design

The final cost of the kit including a radio control security override and the vehicle itself was $433. The final prototype is presented to the client along with full documentation. As the final activity the students give a formal presentation to all the participating Companies, Engineers, and fellow students.

5.2 Wheel Chair Transfer Device

The design need for this problem required the design of a means to help a disabled person to transfer from and to a wheel chair without the help of an assistant. As part of the problem definition the students had to convert this vague description into a more technical specification PDS. Information such as which type of wheel chair was intended, dimensions of the point of transfer for the disabled person, what physical capabilities and limitations needed to be taken into consideration, etc was determined. Once the PDS was completed it was presented to the clients to make sure that they agreed on the terms and scope. As with the other groups they generated 60 conceptual designs, which were then reduced to 15, then to 3 and finally to one by the same process. Figure 5 shows the three finalists. The final design selection is done with the "client" and the detailed design is performed. Idea #3 was finally selected and a working prototype constructed.

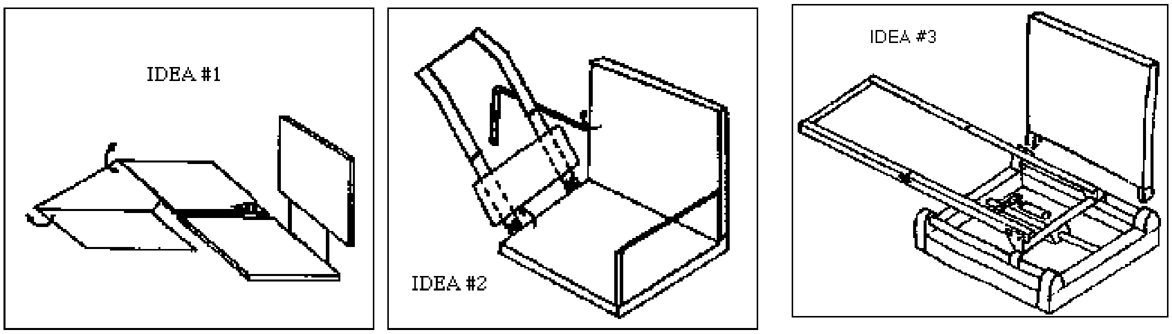

Figure 5 Wheel Chair Transfer Mechanisms

6 OTHER EXAMPLES

Other examples are shown in Figures 6 and 7. A device to aid cuadraplegics in viewing books and magazines was developed, Fig. 6(a) and a mechanism that allows paraplegics in and out of the shower is shown in Fig. 6(b). A sports equipment for the disabled such as the Bowling Assistant is demonstrated in Fig. 7(a). A universal design toy such as the Merry-Go-Round is shown in Figure 7 (b).

Figure 6. (a) Book Viewing Assitant and (b) The Shower Helper.

Figure 7 (a) Bowling Device and (b) Merry-Go-Round

7. CONCLUSIONS

Both the objectives: (1) provide the students an alternative to experience design in a much shorter period with less resources and (2) students have the satisfaction that their work will benefit society and make life much easier to people with special needs were accomplished.

Students were able to realize that their is a difference between a design that works on paper and one that works in the real world. They understood the importance of concurrent design: designing for manufacture, designing within constraints (cost, availability of materials, availability of expertise, and TIME!).

Students experienced hands-on team work throughout a complete cycle of product development. More important many experienced for the first time the interaction with professionals from other disciplines not generally encountered during their previous training.

From the results of the first semester the author decided to move the prototype construction close to the MidTerm. Students still performed the actual manufacturing in a period of approximately two weeks (no mater if it was at the end of the semester or at the middle). The prototype earlier in the development cycle helped define and refine the design. As a result the outcome for subsequent semesters are much better designs in terms of completeness, craftsmanship, and documentation. Students receive feedback and have time to make corrections one last time before the term ends (that is an additional iteration in the product design cycle is possible).

As a final note PRATP has made available the power wheels vehicle design to interested parents such that they may take the design plans and parts list to a Vocational School and have it assembled for them free of charge. Therefore providing a mechanism to access “high tech” at a low cost to people with disabilities. It is noteworthy to mention that various products developed under this approach are currently being patented and licensing offers are being received.

Acknowledgements

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REFERENCES

French, M.J., 1985, Conceptual Design for Engineers, Design Council, & Berlin / Heidelberg Springer, London .

Hubka, V, and Eder, W.E. , 1988, Theory of Technical Systems: A Total Concept Theory for Engineering Design, Springer, Berlin/Heidelberg.

Pahl, G. , and Beitz, W. , 1988, Engineering Design: A Systematic Approach , Berlin / Heidelberg : Springer, Berlin.

Serrano, D., 1991, " Constraint Based Concurrent Design ". International Journal of Systems Automation: Research & Applications.

Serrano, D., 1991, " Design of Solar Powered Vehicles ", IV Minicongreso de Ingeniería y Agrimensura, San Juan, P.R., April 19-20

Serrano, D., 1994a, " Racing with the Sun: New Developments ", VI Congreso de Ingeniería, Agrimensura y Areas Relacionadas, COINAR 94, San Juan, P.R., April.

Serrano, D., 1994b, " The Evolution of Low Cost Sports Vehicles in Puerto Rico ", VI Congreso de Ingeniería, Agrimensura y Areas Relacionadas, COINAR 94, San Juan, P.R., April .

Woodson, T.T., [1966], Introduction to Engineering Design, McGraw-Hill, Inc., New York.