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# A Collective-Learning Approach to Sustainable Design Education*

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*This paper discusses our attempts at implementing a collective-learning approach to sustainable design education in the Systems Design course (sophomore/junior level) at Washington State University. The project involves designing a sustainable airplane by different group of students working on different aspects of the airplane. These sub-systems are developed so that from requirements identification to preliminary design each sub-system group can interact with each other creating a virtual-enterprise within the classroom. Sustainability aspects are currently limited to identifying recycling information and creating a Bill of Material for RoHS (Restriction on Use of Hazardous Substances) certification.*

**Keywords:** collective-learning; sustainable design; RoHS; preliminary aircraft design

## 1. OVERVIEW OF THE APPROACH

DESIGNING SYSTEMS for sustainability involves accounting for a wide range of considerations, including environmental, societal, and economic aspects. Educating students regarding design of sustainable systems is becoming an essential component of an undergraduate engineering education. Current approaches are either primarily focused on very specific aspects of sustainability such as emissions resulting from specific processes and energy utilization in specific manufacturing processes, or general aspects such as Life Cycle Assessment and Economic Input-Output Analysis. Further, the emphasis is mainly on the environmental impact. The societal and economic aspects generally receive little attention. The key challenge for educators is to impress upon the students the multi-faceted and highly interrelated nature of the design for sustainability. Decisions made by different stakeholders throughout the product development process and across different domains affect the sustainability at the system-level.

In order to address this challenge, we present an approach to educating students on engineering sustainability based on the concepts of collective learning. The general idea is to simulate a product development organization in a classroom environment with different student teams representing different stakeholders. A complex product design problem is divided into sub-systems whose design is carried out by different student groups. The teams formulate their design decisions based on the three aspects of sustainability—environment, economy, and society. During this decision formulation phase, the students receive in-depth knowledge about the respective subsystems and their decision formulations. The student teams then interact with each other through their decision models to explore the effect of different decisions on the overall system-level performance. Through this approach, the students can explore the interrelated nature of the overall design problem and at the same time, learn about the other aspects of the entire project that their colleagues worked on. The approach is implemented by bringing together students not only inside the class but also from outside the class. The approach presented in this paper and practiced in the class during the course of this project addresses criteria 3 (program outcomes), outcomes (c), (h) and (k) of the ABET 2009–2010 criteria for accrediting engineering programs [1].

In this paper the research question is to identify if sustainability can be taught through collective learning approach by in a systems design course through a large collaborative project. Currently the measures of success are the student responses, comments and identification of incorrect informa-

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tion regarding sustainability. In future, we would explore more quantitative measures of success.

## 2. BACKGROUND

*2.1 Sustainability*

In recent years, sustainability has become a strategic initiative as industries began to seek novel ways for resource efficiency, ensure compliance with regulations related to environment and health, and enhance the marketability of their products and services. According to the US National Research Council [2], sustainability is defined as 'the level of human consumption and activity, which can continue into the foreseeable future, so that the systems that provides goods and services to the humans, persists indefinitely'. Other authors (e.g., Stavins et al. [3]) have argued that any definition of sustainability should include dynamic efficiency, should consist of total welfare (accounting for intergenerational equity) and should represent consumption of market and non-market goods and services.

Environmental aspects are regulated and controlled using various specifications, such as Restriction on use of Hazardous Substances (RoHS) [4] and Waste Electric and Electronic Equipment (WEEE) [5]. Economic and societal aspects of sustainability are mainly focused on cost constraints and customer requirements. Standardized guidelines for assessing the environmental impacts, called life cycle assessment (LCA), have been developed by International Organization for Standardization (ISO) [6]. By including the impacts throughout the product life cycle, LCA provides a comprehensive view of the environmental aspects of the product or process. Design for Environment is another concept utilized to guide the design process so that the product is environmentally benign.

*2.2 Collective and cooperative learning*

Collective learning and cooperative learning are approaches based on the central notion of active learning through interactions between peers. Johnson and co-authors [7] define cooperative learning as 'an instructional paradigm in which teams of students work on structural tasks (e.g., homework assignments, laboratory experiments, or design projects) under conditions that meet five criteria: positive interdependence, individual accountability, face-to-face interaction, appropriate use of collaborative skills, and regular self assessment of team functioning'.

Collective learning is an educational approach centered on creating environments where the students are actively involved in the process of creating their own knowledge through their individual activities and their interactions with the instructor and the peers, instead of one way instruction from the instructor to the students. The primary difference between cooperative and collective learning is that in cooperative learning, the activities are specifically designed in a top-down manner by the instructors and the tasks are decomposed and assigned to individuals/teams, whereas collective learning is focused on bottom-up emergent process where individuals choose the aspects that they are interested in and define their own interactions with other groups. We believe that such a process better represents real-world mass-collaborative scenarios [8], and is scalable for learning outside the traditional classroom environments. The advantage of this approach is that the learning of the group is more than the learning based on independent activities. Rippel and coauthors [9] adopt a collective learning approach using a collaborative answer to a question for the semester to where students. The approach stimulates individual learning on specific aspects of problem that individuals are interested in. Collective learning is achieved when the students interact with each other and try to integrate their solutions with the solutions of other students.

## 3. DESIGN FOR SUSTAINABILITY

Due to the current climate change scenario, the notion of sustainability has recently gained wide interest. According to the United Nations Environment Program, climate change is affected by various human activities such as land use changes (through urbanization and deforestation) and fossil fuel burning (through transport, heating, agriculture, industry) [10]. Although Sustainability is a common objective of all entities around the world, its realization is difficult as it is engulfed in myriad of political, societal, regional, technological, economical, legal and geological issues. It is also quite evident that sustainable development is a dynamic process by nature [11, 12], as the biosphere and conditions around the world are ever changing and still quite unpredictable. Despite this unpredictability, scientist, governments, industry, consumers etc., have realized that increase in global temperatures is very likely due to the increase in anthropogenic (human) greenhouse gas concentrations. This increase in global temperatures, if not curbed, will have a debilitating effect on the viability of the biosphere to sustain life [13]. To impede and hopefully reverse the debilitating climate changes that have occurred, products should be designed for sustainability.

In this paper, Design for Sustainability is defined as the design of products that are sustainable throughout their lifecycle, similar to the cradle to cradle concept for sustainability put forth by McDonough and Braungardt [14]. In other words, design of products that do not diminish or damage the available natural resources throughout the product's life cycle. As a first step, we are investigating recyclability and minimizing the use of hazardous substances in product design.

## 4. IMPLEMENTATION OF THE APPROACH AT WASHINGTON STATE UNIVERSITY

The project consists of designing two small airplanes by two sections of the Systems Design course at Washington State University. Several students working in small groups concentrate on designing different sub-systems of the airplane. The design process involves a) identification of requirements, b) collective concept generation for different functional requirements, c) tradeoff analysis, d) concept selection and e) embodiment design followed by integration of subsystems into a 3D CAD model of the airplane. The objective is to design a small aircraft that is cost effective, human centric and environmentally benign (conformant with end-of-life of aircraft and European Union specifications such as RoHS and WEEE). Each of the steps of the design is coordinated using a virtual environment over e-learning.

The students are required to maintain a log-book of their activities, create a Gantt chart [15] to monitor their progress, provide a design document and make a presentation at the culmination of the project. The project is scheduled to finish by April 30th 2009. The following discussion describes the overall project and progress made till date.

### *4.1 Overall airplane requirements and sub-systems breakup*

As part of this project the students are required to form groups and then make a case in the class to design a particular class of airplane. The general guideline was to select a plane which can seat between 4–20 passengers. Several different suggestions were made in both the section of the class. Each student then voted for a particular plane, out of which Maule-MX type 6-seater [16] and Cessna Sky hawk type 4-seater [17] planes were selected for section 1 and section 2, respectively.

Table 1 shows the different sub-systems based on the number of students in each section and the type of airplane design undertaken. Each student took part in identifying the sub-systems and formed their teams based on their interest. As is evident from Table 1, one of the sections has a liaison or systems integration group. At the completion of this project, it will be interesting to note and quantify the benefits of having a liaison group. Specifying a particular type of airplane is important so that an overall boundary for design variations in each sub-system gets specified. Due to the level of this class, the students are not required to perform design optimizations and may only use simplified physics based equations to justify the designs and related choices.

From a group discussion in both the sections of the class, the following list (see Table 2) of customer and functional requirements for the airplanes are selected. These requirements are then used to build the house of quality [18, 19] for the airplanes. Furthermore, interrelation of the overall requirements of the airplane and individual subsystem is also investigated. Such explorations give a greater insight to the students regarding the top-down flow of requirements in a complex product development process.

Table 1. Number of students in each sub-systems group for the collective design of eco-friendly airplane

| Sub-systems | Section 1: Maule-MX type 6-seater | Section 2: Cessna Sky hawk type 4-seater |
|---|---|---|
| Fuselage | 3 | 3 |
| Wings | 4 | 5 |
| Engine | 4 | 4 |
| Fuel system | 4 | 4 |
| Flaps | 3 | 4 |
| Rudder | 4 | 4 |
| Landing gear | 4 | 4 |
| Interior | 4 | 4 |
| Liaison/Integration | 5 | – |

### *4.2 Requirements identification*

Each sub-system group then studies the requirements for their sub-system. The realization of the inter-dependency of the requirements between each sub-system is important for the project. Figure 1 graphically demonstrates the inter-dependencies of the requirements of the sub-system of an airplane. Due to the level of this class, only mechanical requirements are shown with bold lines. Dashed bold lines indicate weak controls related dependency among the sub-systems while dashed thin lines indicate weight carrying dependency.

Table 2. List of Customer and functional requirements for the airplanes

| Customer requirement | Functional requirements |
|---|---|
| Fuel efficient | Cabin size |
| Safe | Fuselage/Cabin shape |
| Travel speed | Wing size |
| Durable | Wing shape |
| Uses recyclable materials | Airfoil design |
| Maneuverability | Materials |
| Range (miles travelable per fill up) | Cabin arrangement/Design |
| Take off distance/Landing distance | Engine size/Type |
| Lift/angle of attack/Stalling | Propeller size/Type |
| Cost | Flaps |
| Number of humans | Landing gear |
| Luggage volume/Weight | |

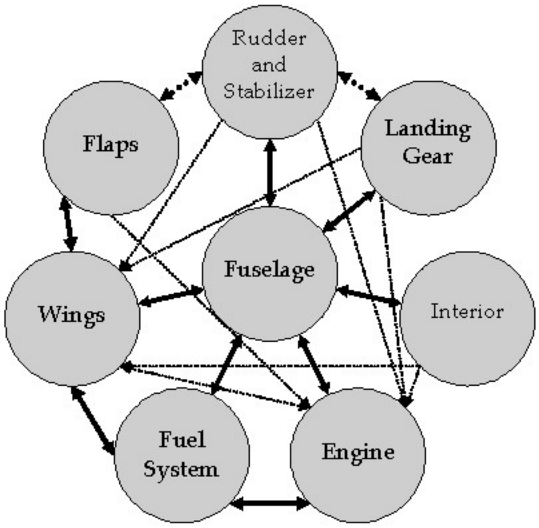


Fig. 1. Mechanical sub-systems and their inter-dependencies for a small Cessna type airplane. Only geometrical and structural inter-dependencies are shown.

By studying documents available online for each sub-system, the student groups create a preliminary specification for their sub-system. Customer and functional requirements for each sub-system are also identified followed by house of quality.

*4.3 Online information sharing*

Currently, information sharing is executed through e-learning website for blackboard type classes. Information sharing include discussions, chats, document sharing, organizing and planning of the design tasks using Gantt Charts.

*4.4 Conceptual design*

At the conceptual design stage the students are only required to develop function structure diagrams and then evaluate different alternatives, which can be found online, for each function for similar type of sub-systems for the selected type of plane. Evaluation of the alternatives can be performed using Pugh Concept Selection [20] or Weighted-Decision Matrix [21], as deemed necessary by the sub-system group members. Material selection is also important aspect of conceptual design, since the sustainability of the airplane is focused mainly on recyclability and hazardous trace element quantification for RoHS.

*4.5 Preliminary design*

In the preliminary design stage each group creates CAD model of their sub-system based on the choices made in the conceptual design stage. Coordinating of the geometric aspects of the junctions between each sub-system is the main focus of this stage. If required, several iterations of redesign might be performed.

Table 3 shows the information that will be collected by each group for their sub-system. Recyclability of the material is quantified using three metrics, percentage recyclability, recycling method and an estimate of ratio of energy (RE) for recycling a given amount of the material and producing the same amount of virgin material. RoHS data is collected by computing the percentage of Cadmium (Cd), Lead (Pb), Mercury (Hg), Hexavalent Chromium (Cr), Polybrominated biphenyls (PBB) and Polybrominated diphenyl ether (PBDE) in the bulk material that can be easily separated from the rest of the assembly.

*4.6 Results*

The students in both the sections of the class were able to successfully design and assemble the planes in CAD environments. Each student gave a presentation of their subsystem, its requirements and relations to other sub-systems in the respective airplane. Only some of the students were able to identify that the RoHS data requires hexavalent Chromium and not any Chromium as was handed out in the Table 3.

## 4. CLOSING THOUGHTS

In this paper we have presented our attempts at implementing a collective-learning for sustainable design education in the Systems Design course at Washington State University. We have implemen-

Table 3. Preliminary Eco-design quantification, table to be filled by the students, through recyclability and RoHS data collection. RE stands for the estimates of ratio of energy for recycling a given amount of the material and producing the same amount of virgin material

| **Sub-Systems** | **Recyclability information** | | | **RoHS data** | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | % | Recycling method | RE* | %Cd | %Pb | %Hg | %Cr | %PBB | %PBDE |
| Fuselage | | | | | | | | | |
| Wings | | | | | | | | | |
| Engine | | | | | | | | | |
| Fuel system | | | | | | | | | |
| Flaps | | | | | | | | | |
| Rudder | | | | | | | | | |
| Landing gear | | | | | | | | | |
| Interior | | | | | | | | | |

ted this approach in Spring 2009 utilizing a project that involves groups of students designing sustainable structural sub-systems for an airplane. Sustainability was primarily focused at only identifying recycling information and creating a Bill of Material for RoHS (Restriction on Use of Hazardous Substances) certification in this project. Students follow the overall design process through requirements identification, conceptual design and preliminary design. Collective learning occurs when the students interact and attempt at learning new concepts regarding the design or sustainability of the sub-systems of an airplane. We observed that this method in general provided a challenge to the students and increased their understanding of the functioning of large industrial enterprises.

Through this paper we have utilized the previous efforts in collective learning in a preliminary way. Teaching decision making in a collective learning environment provided students with a valuable experience they are going to face in the real world. In the current version of the project, we used end-of-life for quantifying sustainability aspects. Although, the students' responses were quite positive for the current project with collective learning and sustainability, in future sustainability aspects will be accommodated at each stage of design from requirements specifications to the final design stage.

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