A Collaborative Product Development Teaching Resource

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Abstract

Product Development is an important topic for many engineering courses and educational programs. It deals with all the necessary steps to bring new or redesigned products to the market. Although product development is practiced in many different ways, there are some common elements that can be taught by universities to prepare students for jobs in industry. In this study, a globally available software was tested in a product development project, as part of an undergraduate course for Mechanical Engineering students. The project entailed development of a liquid container for use in developing countries or disaster areas. The software, CES EduPack, consists of a combination of materials and manufacturing process databases, eco-performance indicators, as well as computer based selection and visualization tools. This platform of comprehensive and comparable data provided by the software, combined with visual charts and Eco Audits, facilitates the communication and collaboration within and between project groups. This is useful e.g., in concurrent engineering or global engineering. In the case study, we confirm that the computer based approach employed could be used to facilitate collaborative learning and identify, in particular, three areas related to the product development process where the software has been a successful resource.

Keywords: Product development, project based learning, collaboration, CES EduPack, Materials.

1. Introduction

A traditional technical design process starts with the identification and specification of the product function [1, 2]. A description of concepts and their elaboration into possible layouts is followed by refinement of the design and a final specification. In this process, the goal is to fulfill all design requirements for a functional product to be manufactured.

One of the challenges during the product development is to balance Function, Shape, Material and Manufacturing Process aspects [3]. In Design for Manufacturing (and Assembly) [4] and in Concurrent Engineering, these and other aspects are considered simultaneously and early in the design process [5]. Whereas the shape of the design is usually elaborated using CAD/FEA, there is also a need for linked material and manufacturing process selection tools.

This study considers the use of an established and widely available software to support teaching in Engineering, Materials Science or Design. CES EduPack (referred to as the software), was originally developed at the Engineering Department of Cambridge University (UK) for teaching [3], but has evolved into a family of tools used for materials-related applications in research and industry [6]. This software is well known for materials and process selection within technical design [5]. However, it is also useful in the wider scope of product development [7].

Since product development is creative, collaborative and time-constrained, it appears suitable for project based learning in student groups (supplemented with lectures and/or supervision). If a multi-disciplinary approach is desired, product development contains many interesting components: cost, design, eco-performance, manufacturing, marketing etc. For multi-disciplinary groups and groups working in parallel or in sequence on a joint project (e.g., global engineering), a collaborative platform would be useful. This aspect, in particular, has prompted us to explore a computer-supported methodology in a real student project.

![Figure 1 Main capabilities of CES EduPack related to the technical design process [3].](image-url)
We have previously reported on an approach for project based learning that is suitable in the context of product development [7]. In this paper, we elaborate on how one project group in a class of third year undergraduate students of engineering successfully used the software in the creative product development teaching/learning process. Their project was the development of a liquid container that can also serve as construction element for use in developing countries or in disaster areas. This case study and the assessment of results are described in Section 2 and details of how the software was used in product development are given and discussed in Section 3.

2. Teaching Methodology and Assessment

2.1 Project based learning

Several small groups of undergraduate Mechanical Engineering students of at University West (Sweden) participated in this case study. CES EduPack was used as a main resource during a product development process with a project based learning approach. The software had been introduced to all students in a previous course in Materials Science and Engineering.

The Design and Product Development course ran part time for a total of 20 weeks. There was weekly project consultation and supervision by the instructor. Initially, the students were given the task of identifying an opportunity for a new or substantially improved product, having some kind of sustainability profile. This idea was elaborated on using the Ulrich-Eppinger product development model [2]. The selection of concept for final design was based on how well it fulfilled requirements, as identified by the students through market analysis.

All groups in the class had access to the software but one group of 4 students was particularly monitored since they decided to work on a relatively simple physical product (few components), where materials selection was a key factor. The use of the software for this group was observed and documented during the project. The other groups chose not to use the software to the same extent.

The examination of the project and assessment of the results by the instructor was carried out under an outcome-based Curriculum framework, as specified by the Bologna process [8]. In this context, particular emphasis is put on constructive alignment [9] between (a) intended learning outcomes, as specified by the course syllabus; (b) the teaching and learning activities within and outside of the classroom; and (c) appropriate assessment of students at the end of the course. The use of the software relates closely to (b) Teaching and learning activities in the alignment model

2.2 Student assessment

It must be stressed that the software alone will not necessarily make students achieve the learning outcomes, but rather how it is used, in conjunction with learning activities. This particular software, though, is designed to support learning outcomes relevant for product development and has successfully been used for this [10-12]. Three examples of required learning outcomes in this particular course on Design and Product Development, which must be demonstrated by the students in order to pass, are as follows:

- Knowledge about product development tools and methods that facilitates a structured product development process
- Ability to perform a structured product development project
- Ability to critically evaluate the results obtained in relation to the completed project

As examples, we have chosen one learning outcome from each of the Skills-Knowledge-Attitudes categories used by MIT [13]. These are in close agreement with the format used internally at the Department of Engineering Science, as the case study was conducted. The other required learning outcomes (not shown here) relate to sustainability, presentation skills etc. Students are assessed through written exams containing questions on the contents of the course literature (textbooks and research papers). Their use of tools and methods were assessed weekly with the instructor.

3. Case Study using CES EduPack for Product Development

The basic steps of materials and process selection in the technical design process have been described extensively elsewhere [3, 6]. In this paper, we explore the utility more broadly, highlighting collaborative aspects of the software. Three areas identified especially for enhancing communication and collaboration during the product development process are given in sections 3.1-3.3: (1) the specification of product function and requirements, using the data records and explicit listing of material attributes; (2) the selection of concepts and optimization of properties for the final design using visual property charts; (3) an evaluation of eco-properties of the final product using an Eco Audit for, e.g., marketing but also for further improvements to the product.

3.1 Specification of product function and requirements: the Property Dialogue

In most design processes, the starting point is the identification of needs that can be fulfilled with a new or modified product. During the first stage of idea-creation, for instance by brainstorming, it is important to clarify the product with respect to function and design requirements. These requirements are then translated into constraints and objectives for properties of the product [3]. Based on the student feedback, we have found two direct examples where the software could be used to guide these early stages of the product development.
Firstly, data records of materials and manufacturing processes in the databases contain searchable background information about how their properties are used in applications. This gives students a starting point for concept generation. In addition, it might also trigger associations to new materials or similar applications, for ideas. As an example from the liquid container case study, a simple search for water+container+polymer, using the level 2 database (MaterialUniverse), results in a list of useful materials with associated images and property data, see Figure 2. These are good as starting points for discussions on specifications within project groups and thus promote communication and aid the collaborative process.

![Figure 2 Example of a material data record and candidates for polymer water containers, for instance polyethylene.](image)

Secondly, as part of the selection tool of the software, constraints can be inserted as limits into the list of materials and properties during screening (see Figure 3). The list of properties provided by the software is extensive and organized into subgroups: Mechanical properties, Processability etc. It is also supplemented with built-in Science Notes (not shown), explaining each property and with value ranges for the different material families. The clickable features (property list, value ranges) and notes work like an interactive textbook and facilitates collaborative work within the group by making sure that everyone has the same understanding of definitions, units, measurement techniques etc.

![Figure 3 Limit Stage property listing, including ranges of values for student guidance and with links to Science Notes.](image)

The project group initially identified a large number of steps, through which the intended product passes during its life cycle. For each of these steps, the students identified stakeholders and their specific demands on the product. This enabled the student group to prepare a requirement specification varying over time. For example, during manufacture,
there are requirements related to the processability of the product and for the product use (when transporting or storing water) there are other requirements, such as non-toxicity, low permeability etc. The different demands on the product, through its life cycle, were then compared to existing/competing products in order to find product features not previously covered. Potential customers were interviewed, similar products were analyzed and legal requirements identified through the study of relevant EU-directives.

At this stage, the software proved very helpful for the students through its limit stage selector, providing the students with a list of material properties where each property either directly or indirectly corresponds to one or more requirements on the product. It is well known that customers do not always know what they want, and find it difficult to articulate what they want in a way that translates to technical specifications. Therefore this helps the students to find requirements not specifically addressed by customers or by competitors.

The two examples mentioned above can be seen as Property dialogue support, as shown in Figure 4.

Figure 4 The way early Product Development (middle box) interacts with CES EduPack via Property dialogue.

The list of requirements identified by the group greatly exceeded what other groups in the class managed to identify in terms of quality and level of detail. The advantage of using the limit stage selector tool this way was explicitly expressed by the students themselves. They also articulated the advantage of having easy access to explanatory Science Notes of the software, such as how material properties are measured or tested and which design considerations should be made.

When the group started searching for ideas and possible solutions, the software was not used much. Instead, methods such as Brainstorming and Patent database searches were used. However, at a later stage of the project, when the concept was to be refined, the software was extensively used and new ideas came up. The students then realized that the software could have been used more as a basis for finding new ideas.

3.2 Selection of concepts and optimization of properties for final design: Ashby Charts

When a number of concepts have been created, a screening and ranking process begins, in order to determine which concept(s) to develop further [3]. Even at an early stage, relative material cost or properties like fracture toughness or optical transparency can eliminate concepts. It is therefore a big advantage to have a complete and comparable source of data compiled in the software. It is crucial for a database to provide access to properties of all material families – polymers, elastomers, glasses, ceramics, metals and hybrids – when it comes to comparing and selecting concepts using property charts. Ashby charts are bubble diagrams that display material properties very clearly.

After the design requirements were established and the students had finished identifying possible product concepts, the next step was to screen all solutions to identify concepts that did not meet the essential requirements. Failing concepts were reviewed to see if they could be altered to meet the requirements – and eliminated only if this was not possible. The software at this stage offered the students easy access to complete and consistent material data, as necessary for comparison. If all relevant materials can be plotted in a property chart, screening can be performed easily with graphical methods.

Following the screening, 17 concepts were identified and passed on to a ranking using a Kesselring Weighted Criteria Matrix [14], which takes into account the relative importance of criteria. The students identified two preferred solutions that were subjected to a more detailed analysis including a preliminary Eco Audit as well as a product cost estimation based on selected materials and manufacturing methods. Eco properties of the database (e.g. embodied energy, carbon footprint and water usage per kg of material) are relevant, in particular, when applying Design for Environment or Design for Sustainability methodologies. Again the software was extensively used and allowed the students to explore large numbers of materials and manufacturing methods within a limited time frame. One solution was finally identified for continued work in order to optimize the design.

One of the useful non-graphical features of the software is the link between materials and process data. This enables the students to find theoretically possible manufacturing processes linked to certain materials or, vice versa: materials that can be processed (theoretically) using a certain manufacturing method. This brings together knowledge from previous materials and manufacturing courses to be applied in product development or capstone projects.

Whereas function is specified very early in the technical design process and shape is commonly determined at the concept generation, the strongly linked choices of material and manufacturing processes are typically part of the optimization stage. This particular software has support for selecting materials based on manufacturability or cost, which facilitates Design for Manufacturability or Design for Value approaches. All the above mentioned aspects—Function, Shape, Material and Process—are interlinked and must be considered together before the final design. An estimate of the total costs can be made using the built-in cost model.
The software was extensively used for optimization of the chosen concept. Material performance indices (criteria of excellence) can be used visually in a property chart to rank thousands of material grades and alloys. Selecting the best material and manufacturing method helps a product to perform its function and meet all the requirements at a favorable cost. This is an extensive task, as can be seen from the abundance of materials considered, in Figure 5. It includes exploring many materials and analyzing them from a performance as well as manufacturability, cost and eco-perspective. This was made possible by the students identifying an efficient and standardized working process, enabling them to collaborate, working in parallel, thus covering more combinations of materials and processes. Using a common database and working with the same process ensured that the results obtained were consistent and could be compared. An extensive graphical use of performance indices [3] also helped in the material selection.

![Material Performance Index and Cost Chart](image)

**Figure 5** Example of a chart used by students to visualize a combined property (Density/Strength) and also Price. Light grey bubbles represent materials eliminated by screening. Suitable materials—Polyethylene and PET—are labelled.

### 3.3 Evaluation of properties of the final product: Eco Audit

Whereas, for example, cost, strength, stiffness and weight usually appear as constraints or design objectives, there are important properties of a product which may not be part of the concept selection or may not be explicitly considered in the design requirements. If the focus is on mechanical performance, eco and durability properties, which both relate to sustainability, might be neglected or overshadowed by cost considerations. These properties can nevertheless be considered around the time of product specification, both in teaching and in real life. A property mapping of the final design in relation to alternative materials can generate ideas for further development. It may also at post product design be possible to replace materials with a more durable or “greener”, but otherwise equivalent materials for marketing purposes, such as to respond to previously unknown needs. Furthermore, it is possible to examine life cycle perspectives and compliance with future product legislation, for example concerning toxicity and recycling. An example of a concept container relating to the case is shown in Figure 6 and the Eco Audit of the final design is shown in Figure 7.

The **Embodied energy** and **Carbon footprint** of chosen materials and processes or **Durability** performance can be used to find arguments for marketing or labelling purposes (eco-friendly, water-resistant, Heavy duty etc). The software also provides advice on how to improve the largest bars in the Eco Audit.

![“Lego-type” connector and Cap](image)

**Figure 6** One possible concept for the container.

![Carbon footprint over final product lifecycle](image)

**Figure 7** Carbon footprint over final product lifecycle.
4. Results and Conclusions

The last step in the project was for the students to verify the performance of new products against competitors. The results indicated that the new product would be superior to existing in many aspects and therefore should be competitive on the market. This comparison was properly documented in the form of diagrams and could later on easily be used as a basis for, e.g., developing marketing strategies and preparing sales material.

The group having used CES EduPack extensively during the course, performed better than other groups in several aspects: The requirement specifications that were used as a basis for the development were more thoroughly elaborated having more requirements and better target values. During the meetings with the examiner (M. Eriksson) it could moreover be noted that the understanding of material properties and their impact on product performance was better than for other students in the class. The availability of material data also enabled these students to perform better in terms of materials selection, exploring more alternatives than other student groups and providing better documentation.

Another area where the group performed significantly better than others was in costing. The easy access to material cost data in combination with information on costs related to manufacturing processes enabled the group to make proper cost evaluations of more material/processing options than other groups. This information was used in the concept selection stage of the project (see Figure 5) enabling a better founded selection than other groups in the class.

Based on the qualitative results of this study, the authors conclude that several key elements of a Product Development process can be taught successfully and can be facilitated using the investigated software. Enhanced collaboration and communication is one suggested mechanism for this result. Although this study is too small for strong conclusions, it is worth pursuing and developing this approach for project based teaching. Three main strengths of the software, which was explored as a collaborative teaching resource, are: (i) the specification of product function and requirements by using Property dialogue, (ii) the selection of concepts and optimization of properties for the final design by visual property charts and (iii) an evaluation of eco-properties of the final product using an Eco Audit for communication with the market and further improvements to the product.

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References


Biography

Dr. Claes Fredriksson is a Senior Materials Education Consultant at Granta Design. He has over 15 years’ experience teaching Materials-related subjects to undergraduate and post graduate students in Sweden, Canada, Belgium and the U.S.A, mainly in Mechanical Engineering. After gaining an MSc in Engineering Physics and PhD in Theoretical Physics he worked in both theoretical and experimental research on polymers, metals and biomaterials. He has a passion for teaching and won a grant as part of Sweden’s Excellence in Teaching Programme to enable him to teach in the U.S.A. and facilitate the cross-pollination of pedagogical approaches.

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