UTILIZING COMMERCIALLY AVAILABLE PRODUCTS TO DEMONSTRATE REVERSE ENGINEERING CONCEPTS IN ELECTRONIC SYSTEMS PRODUCT DEVELOPMENT COURSES

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Abstract: *The use of a commercially available product provides a platform for demonstrating the process and value of utilizing reverse engineering concepts in both understanding the product design, and also understanding ways to develop a new product. The value of reverse engineering is readily demonstrated by selecting a product related to the student's discipline, discussing the processes and principles of reverse engineering and then performing those processes on a specific product has provided a platform that allows experiential learning through application of those processes. The laboratory curriculum is designed to give the students a basic understanding of product development stages, capabilities in circuit analysis and then utilize reverse engineering concepts and circuit analysis methods to produce the items necessary for product development. These items include a conceptual block diagram (CBD) as well as a functional block diagram (FBD). Utilizing these tools, processes and items, the students then prepare a series of presentations that demonstrate an understanding of the product and finally a recommendation for possible improvements. This approach is implemented in a single class approach that prepares students for an advanced capstone series where students develop a working prototype over two semesters.*

Introduction

The following paper will illustrate the use of a household product in a laboratory setting to apply the principles of product development. The paper will outline the product development principles as well as the application of those principles in the lecture and laboratory environments. The products being utilized in this classroom have focused on electro-mechanical household devices and have included garage door openers, microwaves and bathroom scales.

Product Development Life Cycle

The product development life cycle is the time in which the product is being created to the point in which the project may cease to be developed anymore. This life cycle has three aspects, business cases, budget cases, and technical cases. The generic business life cycle have two main concepts, the time the product will break even, and the

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return on investments; once this is complete the main business case goals are completed. These cases must be in balance, and must be given equal emphasis at each review to allow it to advance to a new stage.

There are several stages that the life cycle may phase through:

- Exploratory Research Stage
- Concept Stage
- Development Stage
- Production Stage
- Utilization Stage
- Support Stage
- Retirement Stage

The exploratory research stage will allow you to identify the stakeholder's needs, as well as explore ideas and many technologies to improve the product. In the concept stage you will refine the stakeholder's needs, explore some feasible concepts, and then propose viable solutions. In the development stage you would then refine the system requirements, create solution description, you would build the system, and then verify and validate the system. In the production stage you will actually produce the systems, and then inspect and verify those systems. In the utilization stage you will tune the system to satisfy the user's needs. In the support stage you will then provide sustained system capability and feedback; this is continuous until the life cycle is over. Finally in the retirement stage you will then store, archive, and dispose of the system.

In order to advance into a new stage, decision gates are constructed and should be conducted to assure that the product is in place it needs to be. A decision gate can either be accepted, meaning the project can proceed, accepted with reservation, meaning the project will advance with action items included, or unaccepted, meaning that the project cannot advance. Decision gates can consists of needed documentation, models, and designs. If a decision gate is not accepted it could return to many previous stages, put all activity of the project on hold, or even terminate the project.

In conclusion, the product life cycle is the overall time the product will spend being produced and even after retirement. There are several stages that the product will advance through, and in order to continue advancing the product will go through decision gates. At these decision gates the product can be accepted, accepted with precautions, or rejected.

Concept Generation and Evaluation

Concept generation is a key step in product development for any type of engineering project. If this step was omitted from the process, there would be catastrophic repercussions, such as the project team creating a project that is not what the customer needs or wants. Therefore, it is incredibly important not to rush into the manufacturing process. With adequate concept generation, potential problems can be avoided in later stages of product development that otherwise might have been overlooked. The processes that make up concept generation include the following:

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a. Evaluate an Existing Product

By evaluating an existing product in the laboratory environment, the engineering student is able to see how a fully functioning end product works. In this step, the engineering student is able to decide what components and functions they like and dislike about the existing product and then determine if the components will be included in their own product design. This gives the engineering student a better understanding of the overall scope of the project and shows the necessary components needed to create a successful end product.

b. Market Research

Researching the current market gives the student a good idea as to any voids in the marketplace that could potentially be filled by their product. Market research provides the student with information regarding demand, competition, and size. Knowing these factors allows for a better understanding of financial opportunities and how many competitors share specific markets.

c. Competitive Analysis

Sizing up the competition is vital to understanding the product's chances of being successful. It benefits the student to find a market that has weak competition. By analyzing possible competitors, the student gains insight as to the competitors' strengths and weaknesses and if the student can compete successfully in the market against those competitors.

d. Customer Base

Understanding the target market is the last step before development. The target market is the intended buyer of the product. Analyzing the customer allows the engineer to know what features the customer values in the product. A good understanding of consumer needs and wants could potentially be the difference between the failure or success of the product.

e. Concept Development

Taking into account the information gathered from the previous four steps, the student engineer is now ready for concept development. If all the steps were fully performed, the engineering student should have a good idea of what their final product should include and the potential profit that the product provides.

The students take the household device as assigned (a bathroom scale, garage door opener or microwave for example) and are asked to generically look at that product via

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web searches, etc. the students are then asked to prepare team presentations in the areas of existing products, market research, customer base, and concept development.

Business Case and Business Planning

Having a Business Case, as well as having a Business Plan, will provide the engineer with a goal when creating a project, as well as being a way to ensure that the time and resources are being put into the best projects. Having a Business Case can help you create or acquire a new brand of product, rebrand or help extend the life of an existing product, as well as a plan for corporate sustainability. By having a business plan an engineering student can map out the actual financial steps necessary for the project's completion. These tools are an important ongoing step in the design process; an engineering student will refer back to their Business Cases and Plans constantly, and keep editing and adding more to them throughout the entire process.

A Business Case is a portion of the development cycle in which to aid in the decision making progress. This could be a plan of where the time should be put into the project, or where the resources towards the given project will go. The goal of the Business Case is to provide a plan that shows the benefits, costs, and needs for a project, and will convinces a company to invest and continue to work on it. In order to build this Business Case, you should first have information on the process of the product or future products, strategies, and research of the gate criteria.

The process of the product should include formal information on its development. Knowing how the product will be developed will allow the engineering student to plan how much time and resources will be needed for this stage in the project timeline. Having up-front research and data for the product is also very important. If you are starting the project without any information, the project will have a higher possibility of failure.

Having some strategies for the project, such as setting goals throughout the process, or knowing where to focus your resources, will make the projects more successful. If you set goals, or deadlines, you will be sure to manage the time and resources of the project and overtime gain a full understanding of the overall project. Having some type of goal will make the overall project process smoother and more efficient. Knowing where to use your limited resources is a good strategy to help in the future. This will give you more flexibility with your resources, as well as reduce the time and money you would be putting into the project.

Knowing gate criteria for your Business Case will make the project successful in the future. In the Business Case you must understand the market of your product, how it might perform financially, and technical background. Understanding the market of your product will give you the information of what the customer may need, and what competitors there may be. From this information, you can give sales estimations, operation costs, or the potential revenue. If the outcome financially of the product looks bad, you may want to rethink the project. Finally, you must think if the project is technically feasible, or if you have the skills or resources to complete this project. If the project is impractical, or you may not have the manpower, or equipment to complete the project, the

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project may not advance.

Once you have all this information you can then build your Business Case. To build a Business Case you must first identify the business drivers and the investment objectives. Then, you must identify the benefits of each objective of the project, and to then organize these benefits depending upon the necessary moves. Organization changes that will provide any benefit towards the project should also be identified. Finally, you must then quantify the benefits and costs to determine the overall project value. This value will allow you to make changes previously in your Business Plan, or give you a projected outcome of the overall project.

Throughout the design process the engineering student should avoid purely focusing on the financial aspect of the project. This can lead to unrealistic market conditions, generous financial projections, inferior products, or a poor image brand. An engineering student should understand that there's more to making a product than just money, you must enjoy creating and building the product as well.

The students prepare a business plan and business case for the selected household appliance. In the case of the bathroom scale, students determine the market segment they are interested in and what discriminators their product will have in the market. Students typical discriminators are price point (low cost) or features (Bluetooth capability, user data storage, etc).

In summary, a Business Plan and Business Case can provide the engineering student with background and strategies that they can use to make the project more successful. These plans can also be used as a deliverable to a senior manager, or advisor to track where the project is in the design process. By using market, technical and financial analysis an engineering student can better the project, and have a better chance of success, or approval. Finally, these plans can be used as proposals outside the product development, having the layout of your project can help you impress higher management and even acquire more projects.

Design

During the engineering design process, several techniques are used to create and develop concepts. A product design team has the option to create a product from scratch using their own designs, concepts, and abstractions, forward engineering. Another option is to analyze a similar technology to ascertain how it was designed and operates, reverse engineering. The latter offers the ability to better understand how a product works, correct errors and limitations in existing products, evaluate one's own product to understand its limitations, create documentation for the operation of a product, and transform obsolete products into useful ones by adapting them into new systems. As mentioned before, several commercial products such as bathroom scales have been used to teach the concept of engineering design. The following will make constant reference to these products as used as instruments of instruction.

The first stage of reverse engineering, "prescreening," is to determine what product will be scrutinized. This is where "black box" reverse engineering takes place. Black box

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reverse engineering is where the systems in a product are observed without examining the internal structure of a device. Using the bathroom scale as a customer would and performing research on how a bathroom scale works are examples of black box reverse engineering. In both cases, the functions of the product were investigated without making any changes to the product itself. The purpose of prescreening is to find a product which closely matches the interests of the reverse engineering project and to begin work on understanding how the product functions. The next stage is the disassembly of the product and characterization of the system, "white box" reverse engineering. As the description suggests, this is where the inner workings of the system are examined and documented. This is a more extensive study of the functions of a product via disassembly or other methods of examining the interior. White box reverse engineering can be destructive; however, it provides the best information about how a product works. The third stage is the verification of data gathered in the second stage. This is done by testing the system, creating prototypes, and experimenting with the results. The final stage is the introduction of a new product to the market. The new product should feature innovations of the original product with competitive designs and capabilities.

After analyzing how a product or system works, the next step is to document what was learned in the reverse engineering process. This is done two ways. First, a conceptual block diagram is made. This is a generalized depiction of the overall function of a system. The reason for creating the conceptual block diagram is to learn how to show final product in normal operation. Second, a functional block diagram is created. It shows the overall engineering design of a product, all of the physical subsystems in a design, and the interfaces between subsystems in terms of physical connections and protocols.

The last step to designing a product is to determine the cost of production. This includes the parts, labor, and shipping needed to construct each device. Depending on the scale of production, it may be necessary to estimate the cost of many products and then average the cost per unit. In the bathroom scale example, this was done by shopping for parts in quantities greater than 100. Then, the average cost per part was calculated before summing together the cost of all parts. Depending on the complexity of the design, the cost of labor, based on minimum wage, was added. The pricing step provided a rough estimate of the production cost of each bathroom scale.

It is important to consider the legality of reverse engineering. After all, it involves using someone else's knowledge to make a product or system. However, reverse engineering is a legitimate form of discovery both in legislation and court decisions. The Semiconductor Chip Protection Act (SCPA) explicitly allows semiconductor circuit designers study the layout of other circuits and incorporate that knowledge into the design of new chips. In addition to law, there are several Supreme Court cases where the court has decided that reverse engineering is a legal method to begin the design of a product. For example, reverse engineering was defined in *Kewanee Oil v. Bicron* as "a fair and honest means of starting with the known product and working backwards to divine the process which aided in its development or manufacture." In *Bonito Boats. v. Thunder Craft,* the Supreme Court decided that "the competitive reality of reverse engineering may act as a

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spur to the inventor, creating an incentive to develop inventions that meet the rigorous requirements of patentability." These examples validate reverse engineering as a legally acceptable method to understand, design, and produce a product.

Support

An engineer will have to provide help and support for the product they have developed. This support may include the company providing an instructions manual to allow the customer to refer to if any simple problems. The engineer could provide any type of maintenance if the product is damaged, where the engineer may go onsite to maintain or fix problems. The engineer may also provide online or phone maintenance, where the customer may contact the company and communicate through the problem.

Maintenance will take place in the ongoing support stage of the project life cycle, and will typically continue until the product has reached the retirement stage. In the retirement stage, the product should be stored, archived and disposed due to inactivity. In a real life example, we could say a product that is discontinued would not have any more technical support due to there being no more engineers making the product.

Having completely disassembled the bathroom scale, the students then develop a support plan that analyzes which components will be replaceable and what level of technical support will be provided for the end users.

Conclusion

Product development is a complex process that is important for students to grasp. Utilizing the methods above and the theories and methods provided above, has The use of commercially available products offer a platform for demonstrating the process and value of utilizing reverse engineering concepts in both understanding the product design, and also understanding ways to develop a new product. **Utilizing a product that has a relationship to the students discipline helps to readily demonstrate t**he value of reverse engineering, discuss the processes and principles of reverse engineering and then perform those processes on a specific product has provided a platform that allows experiential learning through application of those processes.

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