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# Teaching Design Innovation in Product Engineering Classes

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# TEACHING DESIGN INNOVATION IN PRODUCT ENGINEERING CLASSES

Innovation is a broadly defined term and anything from an incremental improvement to a revolutionary new design can be classified as innovative. In product engineering classes we commonly will have one or more team projects where the team designs a new product, and the expectation is that the design will be innovative. The instructor faces two challenges (i) Providing specific product-focused guidance to the team so that they can make timely progress, and (ii) Catalyzing the innovation thought process in the team process. A common trap is that the application is novel (e.g., a breakthrough bio-medical device) but the design itself is not. This presentation highlights methods that have been successfully used to promote design innovation in course team projects. Three methods that can easily be integrated into the classroom are illustrated: (i) Structured definitions of innovation with validated examples, (ii) Guided ideation and innovation using design analysis tools, and (iii) Innovative redesign of existing products that are readily available in the market.

## 1. INTRODUCTION

Almost all design engineering courses will include a team project in which students are presented with a specific design objective. A core objective of these projects is to have students integrate engineering principles into a working device so to provide users with a defined functional utility. Project complexity is determined by the number of components in the design and the number of different technologies or processes that are integrated into the product. The product functional requirements (FRs) or utility are a minimum set of independent requirements that completely characterize the functional needs of the product in the user domain. Design education requires instructors to motivate and instruct students on how to design build innovative ideas and concepts into their project outcomes. In product engineering classes we commonly will have one or more team projects where the team designs a new product, and the expectation is that the design will be innovative. The instructor faces two challenges (i) Providing specific product-focused guidance to the team so that they can make timely progress, and (ii) Catalyzing the innovation thought process in the student team. A common trap is that the application is novel (e.g., a breakthrough bio-medical device) but the design itself is not. We need to train students on how to explore and implement innovative design ideas. This will ensure long-term success in their professional careers. In the literature, there has been much discussion on how to improve design thinking in courses and increase innovation (Melles et al, 2012; Seidel et al, 2020). Four modes of pedagogy are identified by Seidel et al (2020): experimental, analytical, disciplinary, and interdisciplinary. They suggest that all four modes be integrated into teaching to ensure innovation, and the methods described here follow that approach.

This paper presents approaches that have been successfully used to promote design innovation in course team projects. These methods have been tested by the author over several years in both graduate and undergraduate classes. Figure 1 introduces three sequential steps that instructors can pursue in achieving the innovation boost in a product design-related course.

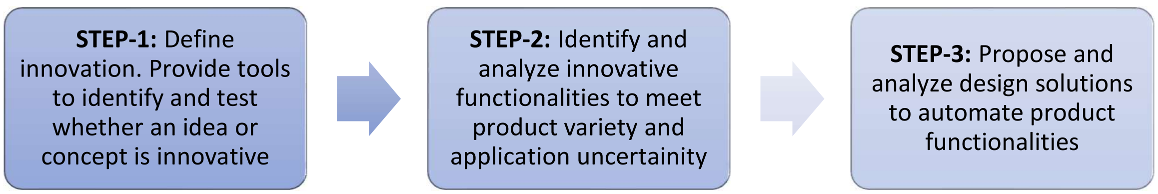


Figure 1. Integrating Innovation into Design Team Projects

In the next sections, we describe in detail specific activities and tools that can be used to implement each of the above steps in a course.

## 2. THREE TYPES OF INNOVATION

Innovation is orthogonally different from progress or improvement, and one must avoid falling into the "innovative because it is better than before" trap. Design courses must train students in the differentiation between 'improvement and 'innovation". In our courses, we have found that providing this differentiation knowledge early in the course (Step-1 in figure 1) effectively leads to higher levels of design innovation in projects and assignments. We recommend providing structured definitions of innovation with validated examples at the start of project assignments. In a recent book, Das (2021) provides a detailed analysis of three types of innovation (figure 2), and these definitions can be used to target student design projects. Initiate the discussion with a dictionary and expert definition, then seek alternate definitions with examples from the class audience.

*Dictionary Definition:* Something new or a change made to an existing product, idea, or field. (Merriam-Webster, 2022)

*Expert Definition:* Executing an idea that addresses a specific challenge and achieves value for both the company and the customer. Where the added value is a huge leap from the present to the future, in that it embraces new concepts and technologies. (Skillicorn, 2016)

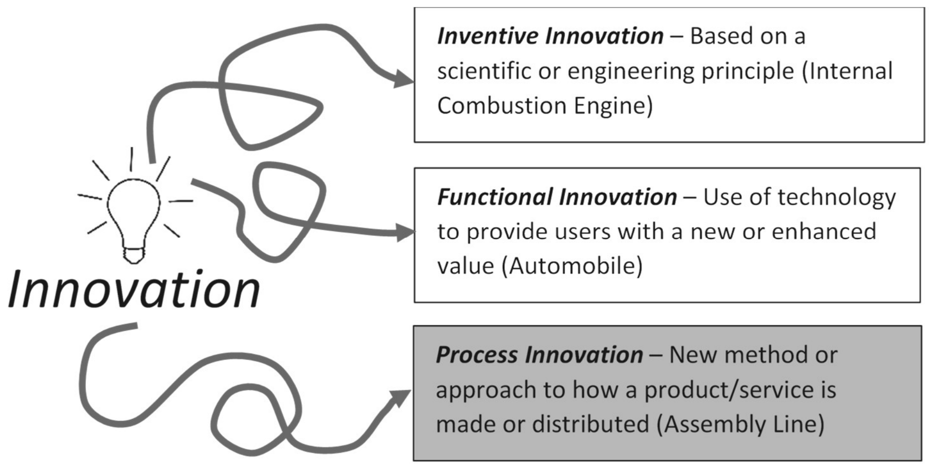


Figure 2. Innovation Driven Value Creators (Das, 2021)

A successful new design will combine several innovations, and these can be classified into one of the three value creators. Inventive innovation is Edisonian and typically originates from a scientific or engineering principle. This type of innovation is the intellectual property of the inventor and is often protected by patents or licenses. A student design project will rarely involve an inventive innovation and is more likely to include functional and/or process innovations. We found that student teams spent a lot of their resources searching for an inventive innovation, often with no success.

When discussing innovation, start-ups, or new ideas, the two words most frequently mentioned are disintermediation and disruption. These two words imply that the delivered product or service is not necessarily new or novel, but rather the process by which it functions or how it is made. We label this as process innovation, and frequently the innovator will leverage existing technology to either reduce costs, improve user efficiencies, or minimize setup time and effort. It starts with identifying an opportunity to disrupt the current process and then the design-build of an innovative solution. The internet is the growth hormone of process innovation, and when mixed with cloud computing the opportunities are ten-fold. Almost every existing product/service can be radically redesigned. Every company should position an Innovation Lookout Team, whose job is to constantly scan the horizon, looking for unexpected threats or opportunities. Why? Experts tell us that innovative ideas rarely come from those vested in the current product. In the case of internet-enabled process innovation, it almost always originates from the outside. Usually, the threats will come from companies that are not on your top-10 competitor list. The innovation lookout team scans the universe of start-ups, researching, and learning from the disintermediators and disruptors.

End the innovation discussion by introducing an innovation test, which would be used by the design team to confirm whether their idea is truly innovative. The test consists of the following three questions:

1. What is the functional challenge the design idea is solving?
2. What is the user value being generated and what is the scale of this value?
3. What is the enabling technology that facilitates the design idea?

If all three answers pass a specified benchmark or threshold, you have a winner. How do you get the student design teams excited about innovation and the associated ideas? As a first step, I suggest you ask them to watch at least three episodes of Shark Tank. The episode on the Ring Doorbell (CNBC News, 2016), is one of the most effective instructional tools. You need to be a swimmer before you can swim with the sharks. Interestingly, a structured design thinking approach to driving innovation in student projects is being aggressively pursued in business school courses (Armstrong, 2016).

## 3. DESIGN IDEAS TO MATCH VARIETY AND UNCERTAINTY

A key design theme of the internet is the optimization of products for every customer. Example: A vacuum cleaner is a generic product, but how person A uses it is completely different from person B. How do we design the product so that it adjusts for A and B differently? Product design classes must instill this design theme in a new generation of design engineers. Commonly this is referred to as the Internet-of-Things (IoT), a formal definition of Physio-Digital Innovation: The integration of digital control and cloud computing into the physical devices so that a wide range of new design opportunities is generated (Figure 3). The next step, therefore, is to promote guided ideation and innovation using design analysis tools.

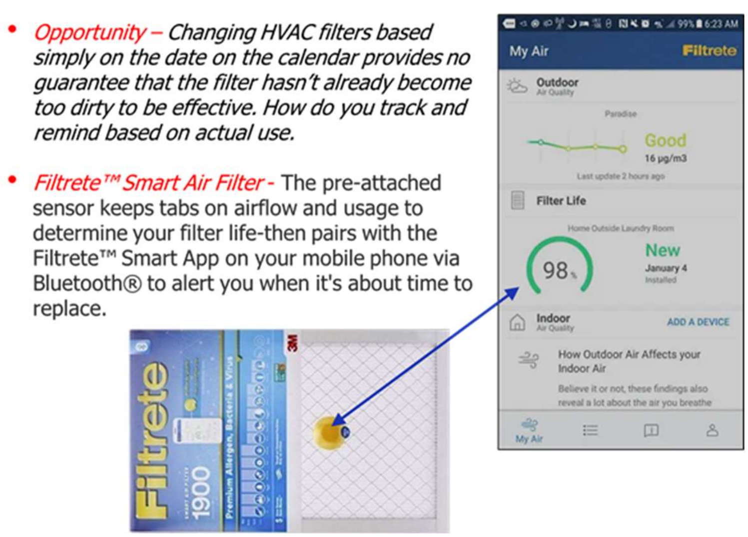


Figure 3. Design Idea Example of Physio-Digital Innovation

Increasingly, future product application environments will be highly variant, high temporal and are characterized by high degrees of input variable uncertainty. Customers are behaving like particles in a fluid flow model and each one follows a different path. Product users are no longer satisfied with the standardized catalog of products, they want products that meet their specific needs. In our classes, we have successfully used The Brownian Multiplier to Idea or BM-Idea tool. Student teams were able to effectively generate physio-digital ideas that were then integrated into their design projects (Step-2 in figure 1). The BM-Idea tool directs the design-build team into an exploration of changing customer trends and then sequentially helps create physio-digital innovations ideas to support customer trends.

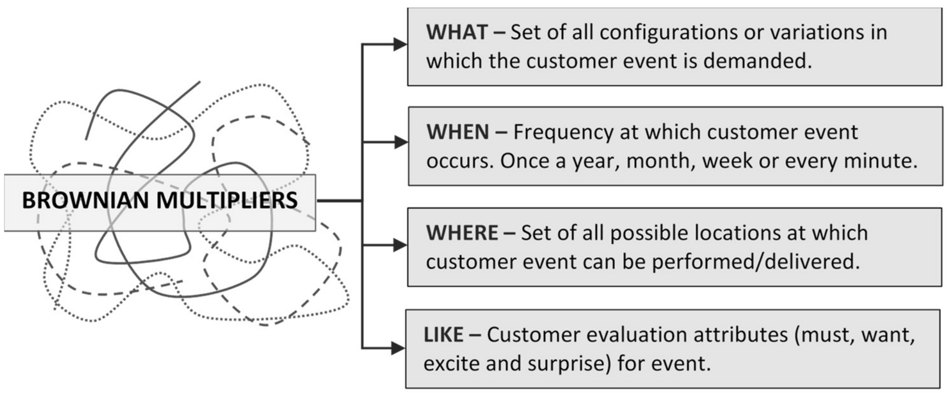


Figure 4. Four classes of Brownian Multipliers (Das, 2021)

Four classes of multipliers are investigated by the team (figure 4). For each multiplier, the team is focused on isolating what functional adjustments will let the product successfully fulfill the wide range of new customers.

*What Digital/Physical Ideas Accommodate the Multipliers?* This is a classical ideation step. The multipliers and why not are already known, the team is tasked with formulating ideas that can seed the development process. The task is not a full design process but only the generation of ideas that confirm the possibility of a doable solution. The ideas are innovation solution statements that later seed the design-build process.

*What is the Critical Intelligence?* Identify the required intelligence for optimal decision-making in the context of digital and physical ideas. A key issue in systems with many decision points is the risk of performance deterioration due to sub-optimal decisions at several points. Several approximate decisions or decisions with weak objective function linkages will lead to performance drift.

The design ideation will answer the above two questions. A completed example of the BM-Idea Tool for a home alarm system is available (Fast Fufill, 2022).

## 4. DESIGN IDEAS TO INTEGRATE AUTOMATION

A second key theme of contemporary design is to leverage physio-digital innovations into design solutions that automate one or more product functionalities (Step-2 in figure 1). Students must be informed on the difference between a classical and a Physio-Digital automation goal.

*Classical Automation Goal:* Replace a human worker with an automatic machine. Net result: lower costs and higher productivity.

*Physio-Digital Automation Goal:* Extends classical automation into the decision-making domain and includes artificial intelligence and machine learning. Partition the product/service into several automation blocks, each of which has a specific operational objective. The automation blocks are closely integrated with humans, both at the physical level and information sharing level.

The programming or coding aspects of the automation is not the project challenge, rather, it's the formulation of the transfer function which relates the input variables to task execution. Three classes of automation are described by Das (2021) and these effectively position the student teams to evaluate their ideas.

*Alpha Automation: Productivity Focus* – Automates a specific task or process such that a human worker is partly or fully replaced. May include sensory and vision automation.

*Sigma Automation: Intelligence Focus* – Automates a specific task or process including intelligent decision analysis, such that a human worker is partly or fully replaced. The intelligence is embedded in computer-coded algorithms which may access both repository and real-time data.

*Gamma Automation: Societal Focus* – Replicates the motions and cognitive behavior of humans or animals. Machines have a humanoid structure, are often equipped with mobility, and can work in teams and alongside humans.

In our classes, we have successfully used automation challenges analysis or the AC-Analysis tool to generate automation ideas and then build the supporting transfer functions. Figure 5 flowcharts the AC-Analysis process, starting with identifying a specific challenge and then transitioning actions and decisions from humans to an automatic machine. It identifies input variables that determine automation task difficulty and evaluates these in the context of situation attributes and then estimates the required machine capability.

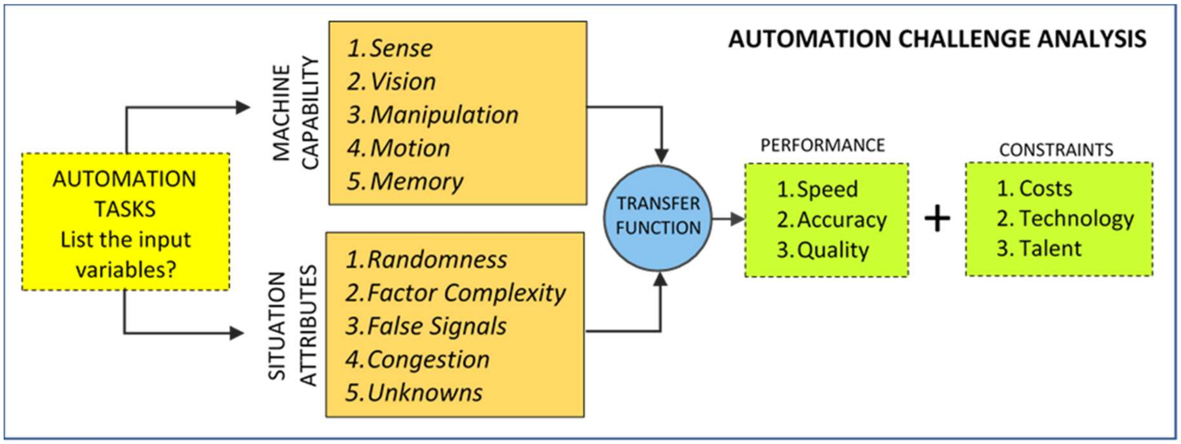


Figure 5. Flow Process of the Automation Challenge Analysis

AC-Analysis helps the team to investigate the challenges associated with an innovation automation idea. The analysis then relates these challenges to target performance and resource constraints. The focus is on a set of tasks or a process, within the product or service, that need to be automated. The task performance is a function of several input factors, and the analysis will identify the control difficulty and performance impact of the factors. Each input factor will influence the difficulty of automating the set of tasks, and the design difficulty can be estimated from five situation attributes. Each attribute and the associated difficulty scale are described below.

1. **Complexity** – Range of possible input values, including small variances in each factor. Example: How many different colors plus variations of the same product (red, blue, dark blue, light blue)?
2. **Randomness** – Uncertainty in the input factor values. Variance and centralization of the uncertainty behavior are measurable dimensions. Example: The number of dark blue boxes in stock ranges from 5 to 50 but 80% of the time there are only 20 boxes (centralized) as opposed to the case where it is 20% each for 10, 20, 30 and 40 boxes (uniform).
3. **Congestion –** The decision granularity in each automation event, as measured by the number of presented entities. Density and overlap in the physical or data situation are measurable dimensions. Example: The average customer order is for 6 items (congestion) and order arrival times of many items are highly correlated (overlap).
4. **False Signals –** Errors in reading an input value, due to environmental errors. Frequency of the errors and the effect on successful completion of the automation task. Example: Likelihood the wrong item (color or size) is picked, possibly due to lighting conditions.
5. **Unknowns** – Situations that are unknown but could become an automaton issue. The probable risk and their effect on the automation project are the measured dimension. Examples: Box is damaged, or a high volume of returned items with different packaging.

The AC-Analysis guides the team is refining the design and increase success probability. A completed example of the AC-Analysis Tool is available (Fast Fulfill Tools, 2022).

## 5. INNOVATING OLD DESIGNS

Student design teams are time-constrained and need to complete their innovative design projects in a relatively short time. An open-ended design process can quickly become time inefficient and discouraging for the student teams. Our experience is that specifying the design envelope early on, significantly improves project output quality. This was accomplished by directing teams towards the innovative redesign of existing products that are readily available in the market. The project assignment could list products that are readily available for purchase, for instance, these could be electro-mechanical products in the $30 to $40 prince range on AMAZON.com. Students could reverse engineer the product, and follow the steps outlined here, to develop a new innovative design that disrupts the original design.

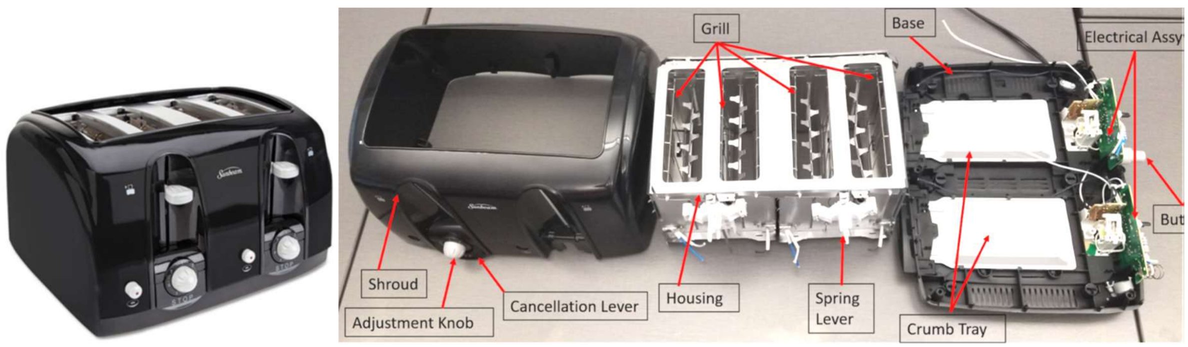


Figure 6A. Current Design of a Toaster

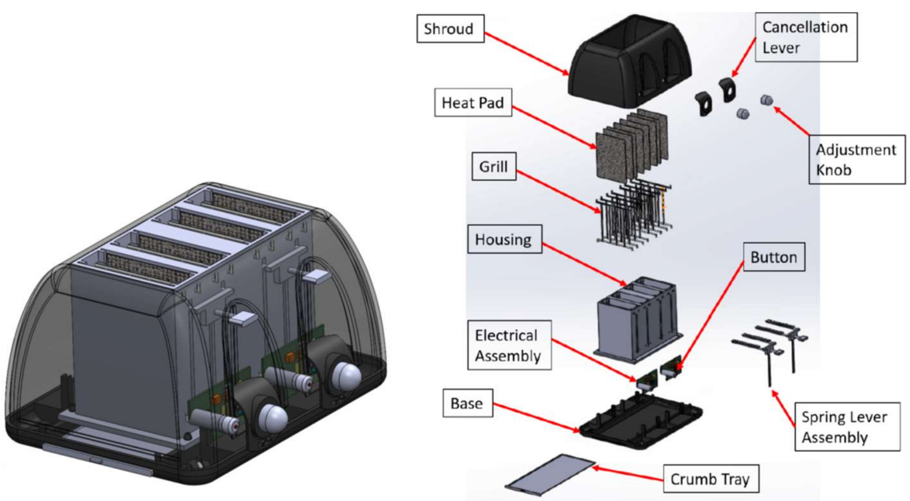


Figure 6B. New Innovative Design of the Old Toaster

Illustrated here (figure 6A and 6b) is a student project which was charged with the redesign of a common toaster. The student team purchased the product and then disassembled it to sketch the old design. In the process, the team became familiar with the functionality of all the components. The net result was that student design learning was enhanced and much more effective compared to traditional approaches.

## 6. SUMMARY

The paper presented a multi-step approach to enhancing the student design learning experience in product design engineering classes. These methods highlight current themes of innovation, variety and uncertainty, and in-built automation in design processes. Two supporting tools, BM-Idea and AC-Analysis were introduced. Supporting documents with proven examples are readily available. We have used both tools in our classes and found that they helped student teams to achieve higher levels of design innovation. The design innovation process presented here requires only minimal effort from the instructor, the supporting documents effectively self-direct the students. The methods have been applied to over 40 project teams over 4 years and we have seen a marked improvement in team innovations. Clearly, the data set is small, and the results may not be achieved in all settings. It is recommended that instructors adapt the methods to their unique course settings.

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