Invention and Creative Design: Getting from Thought to Thing

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Abstract

This paper describes a course entitled *Invention and Creative Design* that is currently taught as part of the Systems and Software Engineering programs at Penn State University's School for Graduate Professional Studies. The course was designed to support several modules in these programs, including a core skill-based module and a module focused on innovation. This paper will provide an overview of the objectives and the content of this course. Specific classroom activities and delivery techniques will be discussed, along with typical homework assignments and the semester-long individual course project. Student outcomes and feedback will be reported as well. While the present audience for this course is composed of working adults, it is highly suitable as a junior or senior level design elective and may be easily integrated into an undergraduate curriculum.

1.0 Introduction

What do the processes of invention, engineering design, and creative problem solving have in common? This paper describes a course that answers this question by examining invention and creative design from the perspective of the practicing engineer. The primary objective of this course is to help students understand what happens on the path from a good idea to a good product, taking both technical and human factors, including psychology, into consideration.

The course explores the fundamental nature of invention and creative design through case studies of familiar objects, from paper clips and pencils to airplanes and modern skyscrapers. These real-world artifacts are approached from a perspective which highlights different facets of the invention process, including design models, analysis, development, failure, economics, aesthetics, social factors, and intellectual property issues. The case studies cover a variety of engineering fields, including aeronautical, civil, environmental, computer, electrical, manufacturing, mechanical, and systems engineering.

One unique feature of this course is its treatment of human psychology and the metacognitive aspects of the design process using M. J. Kirton's Adaption-Innovation theory[3,4,5]. Kirton's theory describes the differences in creative style exhibited by people as they engage in problem solving processes, including engineering design. In this course, students receive individual feedback from the Kirton Adaption-Innovation (KAI) inventory, a highly validated assessment tool that is administered at the beginning of the semester. The results of this inventory are also used in planning small group activities for the classroom that provide the students with further insights in the areas of communication, collaboration, and teamwork. In addition, the course includes a study of various inventors and the individual creative styles they used as they engaged in the invention process. Students compare their own creative styles with these well-known inventors to gain even more insight into their thinking and design strategies. Further details on this unique course component will be presented in later sections.

This paper is divided into ten sections, as follows. Section 2.0 provides a brief background of the course and its development. Sections 3.0 and 4.0 discuss course objectives and an overview of course content (including the syllabus), respectively. Section 5.0 describes some of the delivery techniques used in this course, including specific classroom activities for two case studies: the paper clip and the pencil. Section 6.0 briefly discusses typical homework assignments, and Section 7.0 addresses the semester-long individual course project. Student outcomes and feedback are discussed in Sections 8.0 and 9.0, respectively, and a summary is presented in Section 10.0.

2.0 Course Background

Invention and Creative Design was originally developed as an elective for all students at the Penn State Great Valley School for Graduate Professional Studies. Penn State Great Valley is a special-mission campus in the Penn State University system, tasked with serving the adult learning community in the Philadelphia region. Since its introduction in 1998, *Invention and Creative Design* has been incorporated into several modules that support the Systems and Software Engineering degrees. It may be taken as part of a core skill-based module, which also includes courses in communication and project management, or it may form one leg of a module that focuses on innovation and change. Other courses in the innovation module include *Creativity, Innovation, and Change* and *Engineering Ethics* (both developed by this author). *Invention and Creative Design* also remains open to all students in the School's three Divisions: Engineering, Management, and Education.

3.0 Course Objectives

The main objective of this course is to give students a new perspective on the design process that emphasizes the creative dimension of design (as opposed to purely technical principles) and the accurate representation of such creative behavior in terms of cognitive style[5]. Simply put, one goal is for students to understand both the 'how' *and* the 'why' of an adaptor's highly methodical approach to invention (e.g. Thomas Edison) as compared to an innovator's more intuitive approach (e.g. Albert Einstein). The 'how' is a matter of historical record, while the 'why' requires a deeper understanding of the human mind and its cognitive preferences in creative problem solving.

With such a goal in mind, one must assume that the appropriate technical knowledge and skills required for good engineering design are presented in other courses as dictated by the curriculum. In other words, this course is *not* intended to replace traditional design courses, but instead, may serve as a supplemental course that broadens the students' understanding of design and its inherent complexities.

With respect to both content and delivery, the goals of this course include helping students follow the process of invention from start to finish, through all the potential influences and factors involved, and to do as much of this as possible through active learning techniques. High priority is also placed on helping students to develop enhanced interpersonal and intrapersonal skills, including metacognitive skills (e.g. reflection and self-analysis), and the appreciation of others' creative behavior based on a better understanding of differences in creative style.

4.0 Overview of Course Content

The course content is based on two primary themes. The first theme addresses ten factors that influence the invention or creative design process from initial idea inception through final design implementation. These factors include: the use of design models (or methodologies), the analysis-synthesis relationship, idea development, intellectual property and its protection, failure, technological context, the impact of new technologies, social issues, politics, and systems thinking. These factors are often tightly coupled, and they cannot be entirely separated from the technical design concepts traditionally addressed in each discipline. Nevertheless, they are presented sequentially in this course, with ample discussion devoted to the complexity of the relationships between them.

As was mentioned previously, a unique feature of this course is its treatment of human psychology within the processes of invention and design. This is accomplished through a thorough presentation of Adaption-Innovation theory, as developed by M. J. Kirton[3,4,5], and this forms the second theme of the course[2]. A short tutorial on KAI theory will be helpful at this point.

Kirton's Adaption-Innovation (KAI) theory is based on two assumptions: first, that all people are creative, and second, that all people solve problems. Individuals, including engineers, differ in the cognitive style in which they do so, however, and this has great implications when studying design. In KAI theory and practice, the differences in cognitive style lie along a continuum, which ranges from strong adaption on one end to strong innovation on the other[3,5]. (Please note that Kirton's definition of the word *innovation* is independent of and may differ from common usage[2,6].) The fundamental distinction between the styles can be described in terms of an individual's *preferred* approach to solving problems.

More adaptive problem solvers generally accept problems as they have been defined, along with any agreed-upon constraints. In collecting data, they tend to be exhaustive and favor information and perspectives that are closely related to the original problem structure. When generating ideas, more adaptive individuals prefer to generate a few novel and creative solutions which are relevant, readily acceptable, and aimed at doing things "better". These solutions are often relatively easier to implement than solutions generated by a more innovative person. When evaluating and implementing solutions, the more adaptive problem solver looks for a quick resolution to the problem which will limit disruption and immediately increase efficiency[4]. Thomas Edison is an excellent example of a creative designer with an adaptive cognitive style. Edison was highly methodical and very thorough, and he was strongly motivated by a desire to produce practical, efficient products which had an immediate market.

More innovative problem solvers, on the other hand, tend to reject the original, generally accepted definition of a problem and redefine it. This new view of the problem may be difficult to communicate to others, but may also bring new clarity. In collecting data, the more innovative tend to look outside the original problem structure for different perspectives that they bring into the solution process. When generating ideas, more innovative individuals generally produce numerous novel and creative ideas, some of which are not acceptable to others or may not appear relevant to the problem. Their ideas and solutions are often aimed at doing things "differently". When evaluating and implementing solutions, the more innovative problem solver is less concerned with immediate efficiency and potential disruption, and tends to look ahead to potential long-term gains[4]. Albert Einstein is an excellent example of a creative designer with an innovative cognitive style. Einstein developed many of his revolutionary theories in highly intuitive ways, leaving the hard proof for more adaptive scientists who followed him.

The course syllabus, organized around the two themes discussed above, is shown in Figure 1. The assigned chapters refer to the course text, *Invention by Design* (H. Petroski)[7], which supports the first theme very well. Supplemental material on intellectual property and the KAI is presented through separate readings and handouts[6]. Please note that Penn State Great Valley operates on a 14-week schedule, and each class meeting indicated is a full 3 hours in length.

5.0 Delivery Techniques

In most cases, each class meeting is divided into two segments. During the first segment, fundamental concepts and important points related to the designated topic and assigned reading are discussed. In many cases, discussion questions are provided to the students the previous week as homework items, so students can come to class prepared to voice their views and answer questions effectively.

The second segment of class is devoted to in-class activities that highlight the appropriate case study listed in the syllabus. These activities are typically conducted in small groups of three to five students, depending on class size. Figures 2 and 3 illustrate two examples of these classroom activities, relating specifically to the first two case studies: the paper clip and the pencil. In-class activities may also include the viewing of appropriate video clips (e.g. *The Edison Effect*[12], or *A. Einstein: How I See the World*[11]) and their subsequent discussion, or question and answer sessions with a guest speaker (e.g. a patent lawyer).

The application of knowledge related to the KAI and creative style is incorporated into the small group activities in the following way. The KAI inventory is administered during the first class meeting and scored before the next class. Individual results of the inventory are not yet divulged, however. In the several weeks that follow, prior to the formal presentation of the KAI material in class, students are grouped homogeneously and heterogeneously relative to KAI scores during the case study activities, but without their knowledge. As the weeks progress, they are asked to note any observations about differences in group dynamics, such as ease of communication, reactions to ideas, work efficiency, etc. During the formal KAI feedback session, students are informed of the makeup of the different groups, and a lively discussion of their insights into team dynamics and problem solving ensues[2]. This thought-provoking sequence of events generally proves to be one of the most popular components of the course.

Figure 1. Syllabus for SYSEN 555: Invention and Creative Design

Topics	Text Reference	Meeting #
Introduction/Overview: Design and Invention Thinking Styles	---	1
Case Study Project: Library Workshop	Ch. 1, Handout	2
The Design Process: Models Case Study: The Paper Clip	Ch. 2	3
Analysis in Design Case Study: The Pencil	Ch. 3	4
Development of an Idea Case Study: The Zipper	Ch. 4	5
Intellectual Property: Innovation, Design, & The Patent Process	Handouts	6
“Failure” In Design & Invention Inventor: Thomas Edison Case Study: The Aluminum Can	Ch. 5	7
Thinking and Inventing Styles: KAI and Ideas	Handouts	8
Inventing in Context Case Study: The Fax Machine	Ch. 6	9
High Tech Issues Case Study: The Airplane	Ch. 7	10
Design for Society Case Study: Water Supply	Ch. 8	11
Politics and Complexity Case Study: Bridges	Ch. 9	12
Design of Systems Case Study: Large Buildings	Ch. 10	13
Final Session/Wrap-Up: Project Presentations Evaluations	---	14

Figure 2. Small Group Activities for Paper Clip Case Study

Case Study: The Paper Clip

Small Group Activities

Each group will receive a new and unopened box of “standard” paper clips. As a group, complete the following activities, discussing and recording your results along the way. Your group’s results will be collected at the end of the class period. Your text may be helpful in answering some of the questions. You have one hour to complete these activities.

Task 1: Understanding the Problem

- Take note of and record any available external information: brand name, kind of paper clip, quantity, picture. What other information is provided on the box?
- Open the box: do the contents match what’s pictured or described on the cover? If not, how do they differ?
- Are the paper clips uniform? How would you describe the quality of this product?
- Take out a paper clip and use it (automatically). Note any problems you have in using it.
- Now, derive and write out explicit instructions for its use.
- What material(s) is your paper clip made of?
- What makes a paper clip work? That is, what are the physical principles which explain its function?
- Overstretch a paper clip (i.e. open it “too far”) - what happens? Now, try to return it to its undamaged state and use it. What happens? Why?
- Take a new paper clip - try to bend it across the (4) wires and break it, counting the number of “bends” required to do so; get an average number for your group.
- Now, unbend a new clip into a straight line of wire. Bend this until it breaks, counting the number of “bends” required; get an average number for your group.
- Take a new paper clip - unbend it into a straight wire. Now, reform it into a “standard” clip again (i.e. “make it by hand”). What tools would make this job easier?

Task 2: Finding a New Solution

- Using the box of paper clips, any extra paper clips supplied by the instructor, and any paper clips you brought to class, design a “better” paper clip (one design per group).
- What makes your design “better”?
- How will you test it?
- How will you manufacture it?
- How will you market and sell it?

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Figure 3. Small Group Activities for Pencil Case Study

Case Study: The Pencil

Small Group Activities

Each group will receive a selection of pencils, a manual pencil sharpener, a cutting utensil, and two varieties of dry spaghetti noodles (note the different thicknesses). As a group, complete the following tasks, discussing and recording your results along the way. These results will be collected at the end of the class period, and you will be asked to share them with the class as well. Your text may be helpful as a reference. You have one hour to complete these activities.

Task 1: Understanding the Problem

The objective of this task is to become familiar with the supplies at hand and their behavior. Using the pencils you brought to class, the pencils provided to you, and the spaghetti noodles, complete the following:

- Record all the identifying information you can about the materials collected in your group. Keep the information well organized! Consider each item's name, material content, features, etc. You may briefly examine the original containers for the items provided in class, but remember to pass these along to the other groups as well.

- Experiment briefly with the pencils under different operating conditions, exploring how and when the lead fails and the production of broken-off pencil points (BOPPs). Consider both smooth and "nicked" lead in your investigations (hence, the cutting utensil). Collect, examine, and organize any BOPPs which you produce for use in Task 2.

- Experiment briefly with the spaghetti noodles, exploring how they fail and the conditions under which they fail. Consider how their behavior might be helpful in further investigation of pencils and BOPPs (recall the discussion of *analogies* in your text). Consider both smooth and "nicked" noodles in your explorations.

Task 2: Experimentation

Given the preliminary data you collected in Task 1, your second task is to design (and carry out, as much as possible) a set of experiments, which shed light on the behavior of pencils and the production of BOPPs. You may investigate any aspect(s) of the pencil lead failure problem in your experiments (e.g. effects of size, material, writing angle, impact, etc.), using the pencils and/or spaghetti noodles in your experimentation. Be sure to include and record the following:

- Any assumptions, conditions and/or constraints
- The specific hypotheses you will test
- Experimental procedure/method
- Quantitative and qualitative results
- Conclusions (Were your hypotheses supported?)

6.0 Typical Assignments

Due to the significant time and effort involved in completing the individual course project, the homework assignments for *Invention and Creative Design* are not extensive. For the most part, they involve one or more of the following:

(a) Supplemental readings for particular topics;
(b) Discussion questions based on the text and supplemental readings;
(c) Gathering of special materials for use in the case study activities;
(d) Short writing assignments.

The supplemental readings include materials from the U.S. Patent and Trademark Office on intellectual property, feedback materials for the KAI inventory[6], and occasional articles that highlight the case studies[1,8,9] or particular inventors[10]. The discussion questions require some serious reflection (but are typically not collected), and students are encouraged to participate by assigning a portion of their final grade as “class participation”. Students are asked to bring samples of case study objects when appropriate (e.g. paper clips, pencils), and these items are used to support the in-class activities and discussions. Finally, short writing assignments are occasionally assigned to support the individual course project. For the most part, these writing assignments can be directly incorporated into the final reports for these projects.

7.0 Course Project

The individual course project is a major assignment that supports the objectives of the course in several ways. A complete listing of the project is given in Figure 4. First, the project requires each student to synthesize the topics covered in class and incorporate his or her understanding of those topics into an original case study. Second, the specific requirements of the project lead students to investigate the invention process in more detail than a mere casual interest would inspire.

For example, note that students must consider each of the ten factors which may have influenced the creative design process of their chosen invention, *and* they must also include a justified hypothesis concerning the creative style of the inventor(s) involved. This last requirement has inspired many students to contact the inventors themselves in order to discuss the details of the design process. Based on students comments at the end of the course, these conversations with inventors gave the course material a whole new dimension and encouraged the students to look more actively into personal invention and creative design in the workplace and at home.

From a logistical point of view, the individual course project is weighted 50% in the students’ final grade evaluation, with homework and quizzes each worth 20%, and class participation worth 10%. Short segments of class time are occasionally devoted to small group discussions of these projects, so students can compare methods and sources for gathering data, generate ideas for presentation of material, and generally become familiar with the work of their peers. Students appear to enjoy learning more about the case studies of others when given the opportunity.

Figure 4. Individual Course Project for SYSEN 555: Invention and Creative Design

Individual Course Project

Objective

The objective of this project is for you to develop an engineering case study, focusing on a single patented invention. You will note that your text is a collection of such case studies, so you have plenty of examples to follow! This is an individual project, so each of you will submit your own separate case study.

Choosing an Invention

The invention you choose for your case study must meet the following criteria:

- At least one U.S. Patent has been awarded for this invention *and* you can get a copy of it.
- The invention you choose must *not* appear in the case studies in your text.
- Avoid Plant Patents (these are patents for new varieties of plants and seedlings).
- Choose something of personal and/or professional interest to you!

You may choose an invention from any decade, including those which are very old or brand new.

Case Study Components

As you examine the case studies in your text, you will notice that the following components are common among them. Your case study must include *all* of these components as well:

- Physical laws and principles which explain the fundamental characteristics of the invention (how it works, why it works, etc.);
- People involved in the creation and development of the invention (who did it, how they did it, where and when they did it, why they did it);
- Context, history, and development of ideas which led to the invention;
- Patent history and discussion of specific patent example(s)* for the invention;
- Roles of design principles, analysis, and failure in the invention process;
- Impact of "new" technologies on the invention process;
- Relevant societal and political issues of the relevant time period.

*__Note__: You must include a copy of at least one U.S. Patent which was awarded for the invention *and* a brief analysis and discussion of that patent. Do not simply include it and say, "Here it is!" We will discuss the analysis of patents during the semester, as does your text.

You must *also* include the following items which integrate other topics discussed this semester:

- A comparison/contrast of the design process used for your chosen invention and other standard design methodologies as discussed in class;

- A justified hypothesis concerning the thinking style(s) of the inventor(s) involved.

You may organize and present all the above components in any appropriate order. Please include any other components which you believe are important to the completeness of your case study as well.

Case Study Format

Your case study must be typed (double-spaced) and contained in a binder or report cover. You *must* include the following:

- Title page
- Table of Contents
- Page numbers
- Bibliography of references (with citations in the main text)
- Copy (or copies) of U.S. Patent(s) relevant to your case study

You may wish to put your patent copies in an Appendix for convenience. If you do so, be sure to number these pages as well, and refer to them explicitly in your patent analysis discussion.

A well-done case study should require *no more* than 25 double-spaced typewritten pages (main text - not including the patent copies). This is a guideline, not a requirement. Strive to be both concise and complete in your work.

Deadline

Your complete case study is due on **xxx.** Because of grade deadlines, late submissions will not be accepted.

Figure 4. Individual Course Project for SYSEN 555: Invention and Creative Design (continued)

8.0 Student Outcomes

In general, the expected student outcomes for this course can be summarized under two headings: new knowledge and new skills. New knowledge includes ten factors that influence the invention process, detailed case studies of nearly a dozen familiar artifacts from a variety of engineering disciplines, the fundamentals of Adaption-Innovation theory, and some details of patent law. New skills include the ability to research and write an original case study (a common requirement in many management programs, but few engineering schools), and an improved capacity for leveraging the cognitive preferences of their peers in group settings based on a new understanding of and appreciation for different creative styles.

9.0 Student Feedback and Comments

Student comments are routinely collected as part of the standard course evaluations that are completed at the end of each semester. These comments are made anonymously and include both positive and negative reactions to the course. In general, the students respond very positively to the interactive nature of the class, group discussions, the small group activities, and the integration of the psychology of problem solving into the course content. Most negative reactions relate to the amount of time and work required to complete the course project.

On a positive note, one student remarked:

"This course presents an overview which most of the engineering courses miss – the thinking process in engineering design."

And another student commented:

"My traditional engineering courses to date have been theoretical and problem solving. This course made me think in a new way, in all of the other dimensions that go with engineering other than calculating. I particularly enjoyed the thought provocation of the KAI and how it helped me understand why I behave as I do."

These comments, and many others like them, indicate that engineers do find value in understanding their own thought processes in the context of their discipline.

10.0 Summary

This paper provided an outline and description of a course entitled *Invention and Creative Design* that is currently taught as part of the Systems and Software Engineering programs at Penn State University's School for Graduate Professional Studies. The course objectives were presented, and the course content (including a syllabus) was outlined. Specific classroom activities and delivery techniques were provided, along with a discussion of the semester-long individual course project and some brief comments concerning typical homework assignments. Student outcomes and feedback were reported as well. From the student comments, we can conclude that the course successfully meets its primary objective – to give students a new and creative perspective on the design process.

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