EVOLUTIONARY DESIGN PARADIGM AS A RETENTION TOOL

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Abstract

This paper shows that an evolutionary design paradigm in engineering design education will contribute to freshman engineering design education and consequently to student retention. Evolutionary design represents a tool to contribute to student retention because it addresses student interest, it involves teamwork, it demystifies the design process, and additionally it acknowledges the demands of industry. Evolutionary product design, instead of designing a product from scratch, is often used to improve the product and better fulfill the customers' expectations, while reducing the development time and cost. On the freshman level, it is advisable to focus on the first area, information recovery. As one phase of evolutionary design, reverse engineering lends itself to this end. In this paper, the example of a two-cycle gas weed trimmer subjected to reverse engineering is used to demonstrate how a freshman engineering design program can benefit from evolutionary design. Evolutionary design can serve as a retention tool in freshman engineering by appealing to student interest, incorporating teamwork, recognizing the demands of industry, and demystifying the design process.

1. Introduction

Redefinition, innovation, criticism of the undergraduate engineering curricula, and program improvement – these are a growing concern of scholars interested in engineering education [1-7]. This paper shows that an approach of evolutionary design in engineering design education will contribute to freshman engineering design education and consequently to student retention.

According to the National Science Board, the U.S. is not keeping up with other countries in the rate at which college-age youth earn science and engineering degrees [1] even though holders of engineering degrees are needed. This implies a requirement to make earning an engineering degree attractive. Also, universities and colleges are not the only providers of diplomas. Competitors, enabled by IT and "the awesome power of networking," can provide educational programs at comparatively lower cost and often more conveniently than universities and colleges [6]. Consequently, retention of students, especially at the freshman level, is a priority.

The freshman student body is generally not informed enough about engineering. On their study of freshman retention, the authors see as additional challenges in freshman education amongst others limited computer skills, few opportunities for student interactions, and no experience in engineering design [8]. These three areas of learning deficits are addressed by the paradigm of evolutionary design.

Evolutionary design represents a tool to contribute to student retention because it addresses student interest, it involves teamwork, it demystifies the design process, and additionally it acknowledges the demands of industry. Evolutionary product design, instead of designing a product from scratch, is often used to improve the product and better fulfill the customers' expectations, while reducing the development time and cost. Industrial designers as well as design researchers agree that the reuse of design information is much more time- and cost-effective than a re-invention of information [9].

It has been noted that evolutionary product design methodology can be categorized into: the product information recovery phase, the information management phase, and the information reuse phase [9]. On the freshman level, it is advisable to focus on the first phase of evolutionary product design, information recovery. As a part of evolutionary design, reverse engineering lends itself to this end. In this paper, the example of a two-cycle gas weed trimmer to reverse engineering is used to demonstrate how a freshman engineering design program can benefit from evolutionary design. Evolutionary design can serve as a retention tool in freshman engineering by appealing to student interest, incorporating teamwork, recognizing the demands of industry, and demystifying the design process.

2. Evolutionary design appeals to students' interests

Anyone who has ever seen a child disassemble a clock or other appliance, eyes alight with curiosity and excitement can easily see the appeal 'de-construction' holds even for an older person. Reverse engineering, as part of evolutionary design, sparks students' interest because it appeals to the human urge to find out 'what makes the thing tick.' Also, freshmen engineering classes are often teach the theory and the concepts without providing the opportunity to apply these concepts. Consequently, many engineering professionals and researchers would like to see reformed curricula giving freshmen the opportunity to actively apply learned concepts and to "learning-by-doing" [2].

Reverse engineering, as part of evolutionary design, offers an alternative to listening or reading, activities of absorbing, by presenting an opportunity to learning-by-doing, to dismantle and discover. In addition, this 'hands-on' experience, the dimension of touch, adds an aspect to the learning process, which merely 'constructive' design cannot offer. Design from scratch starts in an abstract way. With reverse engineering, students start out with something in hand, literally. Particularly as students move on to Phases 2 and 3 of evolutionary design (the management and re-use of the information gathered), they get a chance to apply CAD software. Again, this is an activity freshmen find interesting and enjoyable.

3. Early exposure to teamwork, including mentoring

Team work is an important an important element in the learning process [10] as well as in the engineering student's professional future [11]. Industry is expressing a demand for graduates skilled in teamwork and communication, in addition to technical competency [4]. Therefore, engineering education needs to emphasize skill in teamwork and leadership skills, including communication. Evolutionary design offers the opportunity to teach/practice these skills. Students with slightly more advance computer knowledge (ideally second year students who just graduated from the design class) could, for example, function as mentors. Being ahead only one year, these mentors would simultaneously constitute a support system for the freshmen – another incentive to stay in the program.

4. Demand for evolutionary design experience by industry

Two studies by engineering educators, one sponsored by the National Research Council and the other by the National Science Foundation, both express the importance to move the curriculum in the direction suggested by our industrial customers [4]. If universities and colleges remain indifferent to the real needs of engineering graduates is that students, students will either become desensitized to real-world needs [6] or, if they realize these shortcomings, they will look for alternatives education providers. Institutionalizing evolutionary design as part freshman engineering design could provide a tool to prepare student for both industry and academia and therefore increase retention.

5. Evolutionary design: tool for design education renewal

The design process is of a unique nature. However we define it, "it represents the bridge between theory and reality" [12]. The process does not evolve in a straight line but involves much to-and-fro. The main cognitive activities sparking an iteration include self-monitoring (like reviewing and evaluating), clarifying, and examination activities, including an openness to finding potential solution failures [7]. As Simon [13] describes it, most of the effort and time is spent in creating alternatives, which did not exist at the beginning.

It is this vagueness and open-endedness inherent in the design process often confuses students [14]. Simon [13] regards the design process as a continual cycle of producing alternatives and testing to assess them, a process that students often find painfully difficult. If at the freshman level the vagueness and open-endedness, the problem space and solution space, are reduced, students will have a more successful and cushioned entry into engineering design. The model of creative design presents the design process as a co-evolution of the problem space and the solution space: the solution space and the problem space co-evolve simultaneously, with interchange of information between the two spaces [15]. In the case of designing from scratch, the solution space and the problem space could be pictured as somewhat foggy areas with wavering borders.

One can apply this image to evolutionary design, too. In evolutionary design these spaces would have centers, the existing product and consequently the problem. In evolutionary design, the student sees a line connecting the dots in the center of the spaces: the design process of the product they are dissecting in reverse engineering. The evolutionary design paradigm, by presenting a relatively focused, structured approach to engineering design, helps those who perceive open-endedness as threatening to a point of turn-off.

In evolutionary design, as freshmen work an existing design spiral downwards, they gain insight into the process of how the product was designed. By guided questioning why the designer made certain decisions, they begin to understand the complexity of the design process and that even a professional engineer must have faced obstacles, made alterations, and changed angles or even approaches. They recognize that open-endedness, complexity and decision changes are normal. In their freshman engineering design class, however these challenges are reduced.

6. Current application

6.1. Introduction

Indiana University Purdue University Indianapolis (IUPUI) is predominantly an urban commuter campus located a few blocks from the downtown city center. Like most campuses nation wide IUPUI is faced with the challenge of increasing retention of all students but particularly entering freshman. In the environment of rising tuition costs, widening gaps in financial aid, lacking pre-college preparation of entering students are some of the challenges students face in the pursuit of their college education. Students face additional obstacles to overcome at a commuter campus. Most of the students hold part time or full time jobs, in the processes financing their education and sometimes supporting families. Also at IUPUI, a majority of the freshmen are first generation college students, who statistically are at an increased risk of not completing their degree. At the School and departmental levels, increasing retention is also a major goal, especially for entering students. Data indicates that the attrition rates are greatest in the first year of school. In the face of these circumstances, it is particularly important to use an approach to design, which appeals to students' interests, incorporates teamwork, and demystifies the design process.

It is important to remember that the following example of application represents only the first phase of the evolutionary design paradigm, the one of information recovery. The choice of the machine used is flexible – preferably one with a good balance of mechanical, electrical, and chemical components. For these reasons, the authors chose a two-cycle gas weed trimmer. This makes it easier to introduce the freshmen to the interdisciplinary nature of engineering design. Currently, the authors are implementing this paradigm at IUPUI.

6.2. Course arrangement

The reverse engineering project was introduced as a hands-on project in freshman course "Introduction to Engineering". The course has three parts, which include Matlab, Pro/Engineer, and electrical circuits. The project is arranged in three formal classroom meetings during the portion of the semester when students have nearly completed the Pro/Engineer portion of the course. The teams also will set up individual meetings in addition to the formal classroom meetings. During the first classroom meeting the instructor introduces the concept of "reverse engineering", and explains the teardown process, including the goals and limits. Students are organized into teams of 5-7 students. The teams are formed during this class meeting and group leaders are identified. A hand out of information regarding the project is provided for each student. Each team then gets a working trimmer. The teams are also provided with components of the manufacturer user's manual for reference. Information on safety in laboratories is highlighted. The groups familiarize them selves with the device. At the end of the first classroom meeting each team prepares a one-page preliminary report summary (speculation) on their thoughts of how a trimmer works. This is accomplished by carefully examining the trimmer externally to determine how it is operated and what it does. This is done prior to any disassembly or reference to user's manual. In other words, what does one think is inside the appliance and how does what is inside it work together to allow the appliance to operate in the way it does? Prior familiarity with the device is not necessary.

The second meeting is held a week to two weeks later and introduces the first step of an ongoing assessment. At this time each group will submit a report on their progress. Students have a chance to discuss with the instructor any challenges they are facing, including team member contributions to the project and documentation activities including Pro/Engineer. The third meeting is held two weeks after the second meeting. At this time each group will provide a 10 – 15 minute PowerPoint presentation to their peers on their results, assemble the unit following their developed assembly manual, and submit their reports. The following are the steps followed by each team:

Step 1: List some design items for consideration

Basic information on the components in assemblies should be recorded. For example, material types and masses are needed to determine part costs. Such basic factors that typically need to be known may include; quantity of parts per product unit, dimensional measurements, weight, material types, primary functions, and cost per part or a subassembly. Each team identifies what information will be collected during the teardown process.

Step 2: Prepare for product teardown

After identifying the design items, one should identify all tools that will be required to complete teardown. Each group will be provided with a set of standard tools. A digital camera will be available for group use during classroom meetings, each group should bring diskettes to save their pictures. This information should be included as part of a written report of teardown.

Step 3: Examine the distribution and installation

Important factors in the product-development decision making process that must not be overlooked are the means used to acquire parts, contain them, ship distribute, and market the product. The distribution packaging of a product should be examined and reported to the design team; often it can be quite expensive. Consumer installation instructions and procedures should be examined for costs, effectiveness and liability. At this stage, students practice to concern themselves with the practices of research and manufacturing, such as environmental concerns and cost.

Step 4: Disassemble, measure, and analyze data

Disassembly is the step commonly considered when thinking of reverse engineering. However, to be effective, this step must be coordinated with measurements and experimentation. Two documents should be created during the disassembly of the trimmer: the disassembly plan (to be converted to assembly manual) and a summary Bill of Materials. The disassembly plan documents when the trimmer was disassembled, who disassembled it, and a step-by-step plan for disassembly. The plan should include a number of entries, including the step number, a description of the procedure, and the required tools to perform each step. This will then be used to provide a manual for reassembling the trimmer. To start the process, pictures are taken and/or any pertinent measurements of the whole assembly before disassembly. Pictures of exploded views and any pertinent measurements of the parts and assemblies are used to complete the data sheets. The final objective will be to use Pro/Engineer to create solid models and drawings of the parts and assemblies.

Step 5: Form a bill of materials

During disassembly, the team should complete a written form that details the product. The data collected in each column of the bill of materials can be useful for subsequent analyses, including cost and performance. This information should be included in the project report. A table is prepared that identifies each component and its function in the context of the operation of the appliance. What does it do? Also included should be a description of how the components operate together to make the device work. The basic questions one should ask include: “How does it work?” “Why is this particular component here?”, and “How does this part interact with other parts in the device?” It might also be helpful to ask “What would happen if this part were not included?” and “Could some other type of component perform the same function?” Such critical thinking leads to the generation of improvements at best, or at least to an increased awareness of shortcomings and inspires discussion and teamwork.

Step 6: Reassemble unit

The unit should be carefully and systematically put together. Components should not be forced to fit, for example attempting to force a round bolt in a square hole. Components are “designed” to fit especially if the user is going to be involved in the maintenance. The instructor will grade the assembly and run checks on completeness with all parts accounted for. Such questions also demystify the design process by drawing attention to the decisions the original engineers must have faced.

An instruction manual for reassembling the trimmer is prepared. This is submitted along with the project report. Each team is required to reassemble the trimmer during class using the developed instruction manual. The instruction manual is graded on effectiveness and clarity. Therefore, the goal in preparing the manual is to provide all of the information necessary for a group of two students to reassemble the trimmer. Teams may use text, drawings, or photos, in the document. It must be a paper document. In addition, teams will not be permitted to use drawings from manufacturer’s user manual. The instruction manual must stand alone without further explanation. This step can make for a fun class time, reminiscent of days gone by when budding engineers still worked on LEGO constructions! A variation could be to let the teams reassemble each other’s machines by following their manuals. This also emphasizes the importance of consumer awareness.

Step 7: Project report and student assessment

All documentation should be included in a report in a binder. The report should have information on how a trimmer works with electrical, mechanical, thermal considerations. Comments on the maintenance of the trimmer and proposed improvements on the design of the trimmer should be included. Drawings should be prepared using ProEngineer. The assembly manual is submitted as a separate document. Teams are also to prepare a 10-minute Power Point presentation of their project for presentation to the class. Apart from the grading for reassembly, the assessment of the reports and other forms of documentation is also important. This documentation, however, serves not only as an assessment tool for the instructor, but as self-assessment procedure for the students themselves. It is by being forced to put their ideas in writing that they realize where uncertainties still exist. At the same time, students familiarize themselves with effective professional communication techniques: plans, reports, and documentation.

6.3. Program assessment

The writings mentioned above also serve as program assessment. In addition, Davis *et al.* [5] present a variety of design assessment processes and scoring scales for program improvement. High quality assessment requires five components [16]:

1. defining clear and appropriate learning targets;
2. identifying users and uses of assessment information;
3. selecting assessment methods appropriate for the targets and uses;
4. sampling to achieve representative results; and
5. preventing distortion and bias.

The "muddiest point" assessment enables students to clarify trouble spots, either in a lecture/information provided by the instructor or in their own learning experience. Angelo and Cross [17] label it as simplest classroom assessment technique imaginable, yet a "remarkably efficient" one, because it requires very little time or effort. Students simply jot down what troubles or confuses them about a limited topic. The "muddiest point" comments can be collected and used for program improvement. We shall also continue with the end of semester course outcome surveys for the project portion of course. Beyond the duration of this grant we propose tracking the four-year retention in engineering. We have baseline survey data for 1999 and 2000 entrants for the degree program.

7. Conclusion

Evolutionary design can serve as a retention tool in freshman engineering by appealing to student interest, incorporating teamwork, recognizing the demands of industry, and demystifying the design process.

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