2006-1918: DEVELOPING A FRAMEWORK FOR DISASSEMBLE/ASSEMBLE/ANALYZE (DAA) ACTIVITIES IN ENGINEERING EDUCATION

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Developing a Framework for Disassemble/Assemble/Analyze (DAA) Activities in Engineering Education

Abstract

Disassemble/Analyze/Assemble activities (DAA), commonly referred to as dissection and reverse engineering, are found throughout undergraduate engineering curricula in the United States. They involve the disassembly, analysis and assembly of an artifact or process, adding 'hands-on' active learning components to the curriculum. Dissection and reverse engineering have been used interchangeably in the engineering education literature, and in course titles. We, however, view dissection and reverse engineering as two different terms, each representing different roles, objectives and outcomes in engineering education. In the context of current DAA activities, we present an organizational framework that places dissection and reverse engineering in the context of desired educational objectives and outcomes.

1.0 Introduction

Disassemble/Analyze/Assemble activities (DAA), commonly referred to as dissection and reverse engineering, are found through undergraduate engineering curricula in the United States. These activities are used to meet, amongst others, one of the recommendations from the Engineering Coalition of Schools for Excellence in Education and Leadership (ECSEL) workshop: "The traditional educational ideology where knowledge is considered as some kind of material substance and good teaching as the efficient transmission of knowledge from (lecturing) teacher to (passive) student, will no longer serve. Reform of engineering education, if it is to meet the challenge of today's professional needs, must open up the curriculum to enable active learning. One way to achieve this is through the infusion of design and open-ended experiences throughout the curriculum." Dissection and reverse engineering both respond to this call by involving the disassembly, analysis and assembly of an artifact or process, adding 'hands-on' active learning components to the curriculum.

Incorporation of DAA activities into the engineering curriculum has been used to achieve several disparate goals. The proposed model, based on a review of the educational, identifies four main goals: to expose, to inspire, to enquire and discovery. The model and each of these outcomes is explained in detail in the following section.

2.0 Framework for Disassemble/Assemble/Analyze (DAA) Activities in Engineering Education

Dissection and reverse engineering have been used interchangeably in the engineering education literature, and in course titles (for example refs[1-4]). We, however, view dissection and reverse engineering as two different terms, each representing different roles, objectives and outcomes in engineering education. In the context of current DAA activities, we present an organizational framework that places dissection and reverse engineering in the context of desired educational objectives and outcomes.

The proposed DAA framework is illustrated in Figure 1. It is composed of two dimensions: (1) guidance provided by the instructor in DAA activities, and (2) engineering knowledge (knowledge beyond high school) necessary to complete a DAA exercise. Guidance could be in the form of oral or written instructions that explain to the student how to conduct the DAA exercise. On the low end of the knowledge dimension of the proposed framework, students are primarily able to answer *how questions* (such as, How is the device put together? How can it be disassembled? How does it work?). Activities in these quadrants should be classified as *dissection.* On the high end of the knowledge scale, activities seek to answer the *why questions* (such as, Why was the product designed this way? Why did the designers choose certain materials?). These activities should be classified as *reverse engineering.*

This point of view is consistent with some definitions for these terms found in the literature. For example, Sheppard and Jenison[6] define dissection as, "disassembling and reassembling an … artifact". On the other hand, Wood et al.[7] state that reverse engineering "… initiates the redesign process wherein a product is predicted, observed and disassembled, analyzed, tested, 'experienced', and documented in terms of functionality, form, physical principles, manufacturability, and assembility." The model quadrants in illustrated in Figure 1 are:

A: **Expose (Dissection)** – Typically included in first and second year courses to familiarize students with physical artifacts in a structured environment. Structure overcomes anxiety students may have with engineering. It increases learning of engineering terminology and vocabulary, and generally only requires high school level of mathematics, physics and chemistry.

B: **Inspire (Dissection)** – Typically found in first and second year courses where it is used to introduce design, graphics, or ground within students the fundamentals from foundation engineering courses such as *statics* and *mechanics of materials*. The format is less structured with students planning their own DAA steps. It provides a self-discovery learning environment.

C: **Enquire (Reverse Engineering)** – Mainly included in third and fourth year courses to ground principles from engineering courses through hands-on activities. Artifacts to be reverse engineered are carefully selected to re-enforce theory. The instructor provides most of the DAA steps to ensure that the appropriate re-enforcement is obtained from the exercise.

D: **Discover (Reverse Engineering)** – Mainly included in third and fourth year design courses. It forms and integral part of the design process, requiring application of 'core' engineering knowledge. It is completed in an unstructured way with students planning their own DAA activities. Mainly applied when an object or process is being re-designed.

Both dissection and reverse engineering related education activities in the context of the DAA framework in Figure 1 are discussed in the next section.

Figure 1. Disassemble/Analyze/Assemble Activities Framework in Engineering Education

2.1 Dissection

The re-introduction of dissection into the undergraduate engineering curriculum in the United States can be traced to *ME 99 Mechanical Dissection* at Stanford in 1991.[8,9] Funded by the NSF sponsored synthesis coalition, the objective of the course was to give mechanical engineering students an understanding of mechanical artifacts by answering the question, "How did others solve a particular problem?" This was followed shortly thereafter by courses at other universities between 1992-1995, based on ME 99, who were part of the NSF-sponsored Synthesis – Iowa State, Hampton College and University of California Berkeley[1] – and Manufacturing Engineering Education Partnership (MEEP) coalitions – Pennsylvania State University, University of Puerto Rico and University of Washington.[10,11]

The development of these courses was in response to a general agreement by US industry, engineering societies and the federal government in the mid-1980s, that there had been a decline in the quality of undergraduate engineering education over the previous two decades, and that universities were graduating great scientists but mediocre engineers.[12,13] As a result there was a push towards providing both intellectual and physical activities (such as dissection) to anchor the knowledge and practice of engineering in the minds of students.[10] Dissection provides hands-on activities that apply engineering principles coupled with significant visual feedback.[3] Since the re-introduction of the first courses, numerous courses that include dissection activities have been developed across the United States (for example see references 14-18).

Dissection activities can provide concrete experiences as part of Kolb's learning model. "Learning by doing" activities encourage the development of curiosity, proficiency and manual dexterity, three desirable traits of an engineer.[14] Dissection gives the students early exposure to fully operational and functional products and processes. Introducing these experiences early in the students' academic careers has been shown to increase motivation and retention.[17] In addition, dissection can be used to provide an awareness of the design process.[9]

Dissection activities are used in engineering education to fulfill one of two needs: to *expose* students to and give them a better understanding of physical artifacts or to *inspire* students in engineering (see Figure 1). They are typically found in first and second year courses. An explanation of the two dissection quadrants follows.

2.1.1 Expose.

The instructor provides background information on products (processes) as well as disassembly instructions, primarily to take apart, view, and reassemble. Activities here provide students with an understanding of artifacts[8] and are used to provide early exposure to fully operational products or processes thereby introducing first-years to the world of engineering in a constructive concrete manner.[14] They give students the advantage of learning engineering vocabulary and terminology.[20] Dissection exercises have also been employed in first-year introductory courses to provide a hands-on experience for women students, to overcome their anxiety about, and intimidation with the use of mechanical and electrical devices.[19] Activities in the expose quadrant provide a gentle hands-on, and fun introduction to engineering. The structured approach – the instructor provides detailed instructions for DAA activities – reduces some of the apprehension students may have towards engineering. Courses in this quadrant typically require only a high-school level of chemistry, physics and mathematics.

2.1.2 Inspire.

In this quadrant DAA activities are more open-ended, with students primarily planning their own DAA steps. Dissection activities here provide an effective method for introducing first-year students to engineering and the design process. These activities have been integrated as part of graphics courses to provide a better learning environment by teaching graphical methods in context of physical artifacts. For example, Iowa State[6] and the University of Texas at Austin[3] perform dissection exercises and prepare solid models, assembly drawings and working drawings by taking measurements of the artifacts parts. The process allows the introduction of topics such as section views, dimensioning and multi-view layout.

At Penn State dissection is used to introduce first-year students to the design process.[21] As part of the process of redesigning an inexpensive consumer product (for example, electric toothbrush or disposable camera) students come up with a dissection plan, then disassemble and analyze the product to get an idea of how it works, and how the different pieces fit together. The Mechanical and Nuclear Engineering Department at Penn State also offers first-year hands-on 1-credit dissection courses. Students are inspired to continue their pursuit of a ME degree by exploring fundamental concepts such as energy and transmission of forces through dissection of bicycles (for example Figure 2), hand-drills and lawn-mower engines.

Dissection activities have also been used to illustrate how Design for X issues are addressed in common consumer products. For example, the University of California-Berkeley have first-year students disassemble Matel® toys to analyze Design for Assembly/Manufacturing issues.[22] The exercise is supported by a multimedia case study describing the design process used Matel®.

The *Exploring Engineering Intuition* course at Stanford is designed to ground fundamentals concepts taught in analysis classes by exploring them in the context of dissection exercises.[23] Eggert[24] employs a two course structure at the University of Wisconsin Madison. The first dissection course focuses on function with the aim of inspiring students about their upcoming education, while the second course later in the students' academic career performs reverse engineering on the same systems using the ‘core’ engineering knowledge acquired since the first course.

Figure 2. First-year students engaged in the dissection of a bicycle (*courtesy J. Lamancusa)*

In summary, dissection exercises, typically offered to first and second year students, require only a high school level of mathematics, chemistry and physics (although some offerings may use foundation engineering courses, especially in *statics*, *dynamics* and *materials*). The DAA steps can either be provided by the instructor or left as part of the exercise. Which one to follow depends on the objective of the activity and the expected outcomes from the course.

2.2 Reverse Engineering

An alternative definition to that previously presented states that reverse engineering is the “in-depth study and analysis of an existing product [or process] to recreate the design decisions and the information developed by the original design team.”[7] From a legal standpoint in the context of engineering, reverse engineering can be defined as, “starting with the known product and working backwards to divine the process which aided in its development and manufacture.”[25] From all the definitions, reverse engineering goes well beyond dissection, and typically requires the design team to develop their own DAA steps and use their knowledge from ‘core’ engineering courses in the analysis. With reference to the DAA framework in Figure 1, reverse engineering activities in engineering education are typically found in the *enquire* and *discover* quadrants.

2.2.1 Enquire

Engineering educators have long noted that lectures though efficient at delivering large amounts of analytical information, encourage passivity in students who come to expect the instructor to provide all the required knowledge.[10] Johnson et al.[26] noted that: “lecturing at best tends to focus on the lower-level of cognition and learning. When the material is complex, detailed or abstract; when students need to analyze, synthesize, or integrate the knowledge being studied; or when long term retention is required, lecturing is not such a good idea.” Other researchers have found that lectures tend to alienate active and reflective learners – the active learners do not do anything, while the reflective learners do not have time to reflect. As a result, both are lulled into inattention by enforced passivity.[27,28] Also, lectures do not adequately take into account varied student learning styles.[29,30] Many engineers are actually "active, visual learners", much better served by active, visual and tactile teaching methods.[31,32,33]

Yet the majority of sophomore to senior core engineering courses exclusively adopt an lecture format. Guided reverse engineering activities would allow students to create a hands-on learning environment where students would re-enforce theory from lecture with concrete experiences, using methods of enquiry to determine the application of the lecture content in an actual product or system. For example, one of the lectures in the junior mechanical engineering design class at Penn State discusses different types of electric motors, their design and ways to select them for a particular application. Students then reverse engineer several different electric motors (guided), using the information from lecture to answer several "why" questions.

2.2.2 Discover

Due to the engineering knowledge required to successful perform reverse engineering, courses that include these activities are found in the third and fourth years, and in graduate school (for example, UT-Austin, USAF, MIT, and RPI). In the *discover quadrant* reverse engineering forms an integral part of the product redesign process, that also includes the usual design steps of understanding customer needs, setting specifications, benchmarking, concept generation, product embodiment, design for X, prototype construction and testing, and production.[34,35] As a result *discover* quadrant activities are usually found in engineering design courses.

3.0 DAA Model from and Engineering Educator's Perspective and Concluding Remarks

From an engineering educators standpoint, the model can be enhanced to include educational goals as illustrated in Figure 3. Educators should first determine *what* they would like to achieve, and then use the enhanced model to determine *which* quadrant and related activities would be best suited to achieve their goals. On-going work is reviewing existing undergraduate engineering course offerings in US schools to compile their stated goals (what they hoped to achieve from the dissection or reverse engineering exercise), activities (the actual dissection or reverse engineering activity) and categories (which model quadrant). This information once complete will provide concrete examples for those looking to incorporate similar activities into their courses.

Engineering design is pervasive across the entire curriculum. A majority of programs start students of with an introductory engineering (design) course in the first-year and conclude with a capstone design experience in the senior year. Yet most programs do not expose their undergraduate students to any dissection or reverse engineering activities. This despite the fact that research related to material representations (as would be experienced through DAA activities) point out their benefit as memory triggers during design. Based on protocol studies Harrison and Minneman[36] described objects as integral parts of design communications. They also pointed out that objects alter the dynamics in a multi-designer setting. Brereton[37] showed that student designers use material representations or prior experience related to those as starting points of design proposals, kinesthetic memory triggers, or thinking props. Logan and Radcliffe[38] found that 83% of design actions involved material artifacts, though relatively few studies have focused on material representations (artifacts) in engineering design. Although both dissection and reverse engineering provide these inherent material representations and benefits in aiding design, they are not commonly used to initiate a design or a redesign activity in undergraduate design courses.

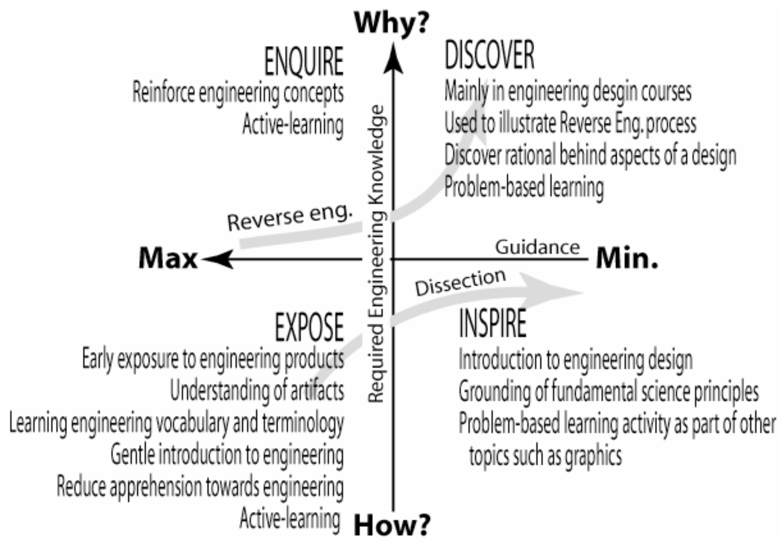

Figure 3. Disassemble/Analyze/Assemble Activities Framework: Engineering Educators Perspective

We hope that the proposed DAA framework that clearly tabulates possible activities, student and instructor requirements with categorized expected goals will make it easier for instructors seeking one of the four desired outcomes to incorporate the appropriate activities in their courses. Future publications, based on on-going work, will provide a comprehensive list of example activities to each of the four identified goals based on a survey of current course offerings in US undergraduate engineering programs.

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