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## **Case Study: Practical Introduction of a Materials Selection Software in a Fundamentals of Materials Science Course**

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**Cassandra J. Wright & John W. Bridge**

### **Abstract**

The University of Washington Bothell's mechanical engineering program, which is three years old, has one course in materials science (Fundamentals of Materials Science) that lays the foundation for the mechanical and capstone design courses. Thus, it is paramount to the faculty that through this course, students gain a solid understanding as to how the materials selection and processing will ultimately affect their final product. Granta CES EduPack is a comprehensive materials science software program that is available to the students at the junior and senior level within the ME program. In past offerings, CES EduPack has been introduced at the end of the course at a basic level to introduce the students to concepts of materials selection. Prior students have not considered the software as a tool for materials selection in their mechanical design and capstone projects in the past, likely due to only having a brief exposure to the software mainly in the fundamental materials course. In order to give students a deeper knowledge to be able to independently utilize it in subsequent classes, the first materials science course module was revised and a second module developed and implemented during the Autumn 2017 term in order to provide students with a more hands-on and in-depth materials selection learning experience. The pair of modules served as a good foundation for the students' mechanical design and capstone sequences. The students indicated that they felt relatively comfortable with utilizing the software. This cohort will be followed through graduation (2019) to determine if there is an increase in usage of the software.

### **1. Introduction**

The School of Science, Technology, Engineering and Mathematics (STEM) at the University of Washington Bothell has experienced rapid growth in both number of students as well as number of degrees offered (currently fifteen degrees and five minors) since its inception in 2013. The mechanical engineering program is three years old and recently received ABET accreditation (September 2017). Within the University of Washington system, students declare the mechanical engineering major at the end of the sophomore year. At many schools, materials science and engineering is a stand-alone or two-course sequence that commonly utilize textbooks by Callister<sup>1</sup>, Shackelford<sup>2</sup>, or Askeland<sup>3</sup>. Here, the Fundamentals of Materials Science (B ENGR 320) course is a one quarter, five credit hour course taught during the first quarter of the junior year that provides the foundation for both the mechanical and capstone design courses sequences. It utilizes Callister and Rethwisch's Materials Science and Engineering<sup>1</sup> text. One limitation of the text, however, is that it does not include a chapter on materials selection.

Selection of materials in homework questions are based off charts with a relatively small set of choices. Utilizing these charts is an efficient way to find approximate values for simple homework solutions. However, the incorporation of software-based materials selection allows the students a broader understanding of how materials relate within a family and to other families of materials.

Therefore, since B ENGR 320 is the only materials science course, it is paramount that this course guides the students to understand the differences among materials families as well as how materials selection and processing will affect the final designed product. Further, it is important that the students utilize this knowledge in the products they design both throughout the program and into their careers.

Due to limited choices of materials within the course textbook, another source needed to be utilized for materials selection incorporation. The authors selected the Granta Cambridge Engineering Selector (CES) EduPack computer program<sup>4</sup> and have made it available to students within the ME program. The software is available to students in the STEM computer lab, the capstone room, as well as a downloadable packet from the course management software (Canvas).

### **CES EduPack Software Program as a teaching tool**

CES EduPack<sup>4</sup> (approximately \$6000/yr for a 100 seat license) is a powerful, interactive materials selection software that allows students to explore almost 4000 materials using utilizing material records, tables of properties, and student-created visual charts. The material records contain a myriad of properties that range from cost, material properties, opacity, and durability in specific acids or bases. Further, the material records contain information that relates to processability and recycling/end of life actions. The students can create Ashby material property charts, which enables them to visually compare materials using one or more criteria (e.g. modulus of elasticity versus cost). The software also contains information about material processing divided into joining, shaping, and surface treatment processes. One of the most useful parts of EduPack is that there are three levels to the database allowing it to be utilized from an introductory to more advanced level. In Level 1, there are only 69 materials with little detail compared to levels 2 or 3 which can contain hundreds of materials with numerous details; this allows for the introduction of the software use without overwhelming the students with the amount of information that can be gleaned from it.

### **3. Initial Incorporation of CES EduPack Software Program**

Starting in Autumn 2015, CES EduPack has been introduced to the students in a single two-hour materials selection lab. The first half of the lab introduced the students to the process of brainstorming material-related criteria for a specific component. For the lab, the students in the class collectively brainstorm the criteria for a carbonated beverage container. After creating a

whiteboard full list of possible properties, the students were asked what specific material to use and they typically realize that narrowing down materials that meet multiple different criteria could be a challenging task. The students are introduced to the importance of ranking of criteria using the Pew method. As the students modify the weight assigned to a property list, the resultant ‘ideal’ material also changes. The concept and examples of Ashby charts were also presented to demonstrate how two material properties or attributes can be utilized in tandem to select an ‘ideal’ material.

The second half of the laboratory allowed the students to utilize the software in groups of 2-3 students to generate Ashby charts as well as explore other aspects of the software such as the material records, which contain information such as cost, material properties, durability, etc. The deliverable for the lab was a completed worksheet of basic materials selection problems.

The software has also been utilized in the first course of the mechanical design sequence (B ME 341: Mechanical Systems Design I) to help reinforce the relationship between materials and design<sup>6</sup>. Students take B ME 341 during winter or spring quarter of the junior year. This course built upon the materials science knowledge and materials selection foundation laid in B ENGR 320.

#### **4. Incorporation of Additional Lab Time for Materials Selection.**

One of the driving factors for the lab redesign is that the authors have noticed that the students do not appear to consider utilizing the software when proceeding through the capstone sequence even though CES EduPack has been utilized in two separate courses (B ENGR 320 and B ME 341). To the authors’ knowledge, it has only been utilized in one project during the two capstone sequences.

It is hypothesized that the students have not considered it for their capstone projects due to the brief exposure in mainly in the fundamental materials course and sporadically during machine design. During Autumn 2017, the faculty set out to create a more cohesive materials ‘thread’ through the curriculum in order to aid the students in associating the information learned in early courses to the latter ones. The specific capstone course outcome this course is laying the foundation for is to “design systems, components, or processes with realistic constraints such as economic, environmental, social, political, ethical, health, safety, manufacturing, and sustainability”. The B ENGR 320 labs were revised to incorporate a second 2-hour material selection lab to provide students with a more open-ended materials selection module that encourages the students to research broader attributes of materials beyond material properties.

In the former B ENGR 320 lab sequence, the materials selection lab was completed during the last week of the quarter. During a mid-quarter lab (week 4-5), each lab group (n=12) was provided four different unknown metals and asked to tensile test them to failure and then

determine the alloy. The students had to first generate stress-strain diagrams from the raw MTS output in order to determine the mechanical properties. The mechanical properties from all lab groups (n=12/group; 48 total specimens) were compiled such that there were twelve samples tested for each of the four materials provided to allow a more accurate set of mechanical properties to decipher. In the past, the students had been asked to make their determinations using their textbook to narrow down the possibilities and then online materials databases such as MatWeb<sup>5</sup> to refine their selection. The students find this a frustrating and sometimes daunting task as materials that meet one set of properties may not meet another thus selecting a material is a highly iterative process. The students self-reported that determination of the samples was time consuming and daunting. Through this lab, they decipher that there must be a better way to narrow down a material's composition and processing.

The authors decided to incorporate the first material selection lab module introducing CES EduPack in week 7 (see Figure 1), one week before the tensile test lab report due date. The authors wanted to give the students time to wrestle with the determination of the material without a process prior to introducing the skill. At the time of the lab, several student groups self-reported having begun the identification process and having difficulties with the identification.

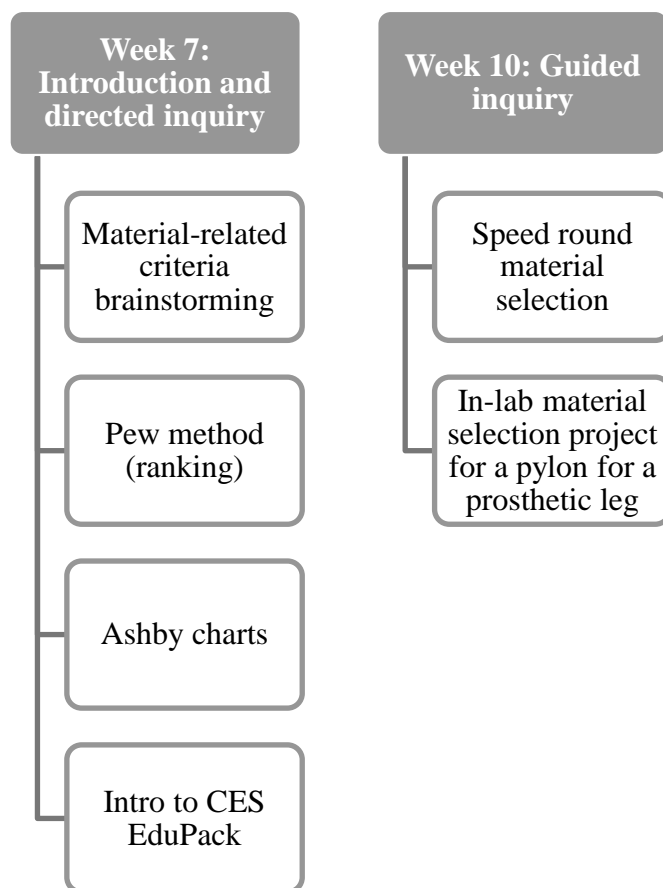


Figure 1: Topics for week 7 and week 10 material selection labs

The lab was taught similarly to the activities described above in the 2015 initial incorporation of CES EduPack Software Program section but with additional time for the students to learn the software. The students were shown how change the level and a brief demonstration of chart creation was provided. Afterwards, the students began to experiment with the software in pairs. The instructor was available to answer questions during the process as needed. The students' software exploration was guided by a lab worksheet where the students were asked to use Level 2 of the software to determine materials that would meet a given set of constraints. And then, the "boss" on the worksheet "changed her mind" and asked for additional criteria several times, which altered the possible material candidates. The students learned how to look at different properties as well as setting additional constraints, which narrowed down their choices significantly. This introductory module introduced the students to creation of Ashby charts, incorporation of limits, as well as utilization of the materials record database.

The second materials selection lab module was taught during the 10<sup>th</sup> (last) week of the quarter (see Figure 2). It was designed to provide each group with time to apply the concepts learned during the first material selection lab. The lab had two primary activities. The first activity involved groups of students completing a speed round of rudimentary materials selection questions. Each question required them to create and interpret an Ashby chart then select the best response of four provided ones. The students responded via a Kahoot<sup>7</sup> quiz. Kahoot is a free online platform that allows the students to respond to multiple choice quizzes using their phone or computer without having to download software. The goal of the activity was to increase their comfort level with the concept of Ashby charts. All but one group responded within the time frame for each question.

The second was a guided inquiry activity where each group was asked to select a material for a prosthetic leg pylon and record the process in the lab handout. The students were provided several pieces of background information including a bulleted list of the material selection steps from the prior lab and a brief oral description of what a pylon is. Additionally, they were provided a general list of material performance characteristics and the steps in materials selection during the design phase, both adapted from Dieter's Engineering Design<sup>8</sup>. Finally, the students were given the general questions to ask in materials selection – how do we select an ideal material for a given application or product. And, what were the primary requirements and constraints? The students were given constraints in the prior lab. But, for this activity, only scaffolding questions were provided to guide the students. The instructor acted as a facilitator by broadly answering questions or having students help other groups in order for all groups to complete the lab.

The following questions were provided in the student packet for the lab:

1. (*time: 10-15min*) In pairs, brainstorm the desirable attributes and properties for the pylon of a prosthetic leg.

2. (*time: 5-10min*) With everyone at your table, compare lists that each groups has come up with. Then, brainstorm together for additional desirable attributes and properties.

- i. FUNCTION (what the component does)
- ii. CONSTRAINTS (the conditions that must be met. Go/No-go conditions)
- iii. OBJECTIVE (What is to be maximized/minimized?)
- iv. FREE VARIABLES (Attributes the designer is free to change)

3. (*time: 5-10min*) Discuss what are the most important properties to consider for your design. Select top three to narrow down your list. Justify why those are your top three choices.

4. Look at the candidate materials for the pylon. Select one using your important properties list and the appropriate material indices (DO NOT DERIVE). Justify why you selected it. Use level 2 of CES EduPack.

Students provided varied responses for question 1. Most groups provided more than ten desirable properties or attributes though a few groups provided fewer than five. As the groups were working in pairs for the first part and as a table (four per group) for the latter part of lab, there was discussion throughout the lab period. The discussions were thoughtful though some groups struggled to stay on task or provide thorough responses as it was an open-ended problem.

To provide scaffolding for question four, halfway through the lab session, the instructor introduced materials performance indices that allows for the assessment of the function of an activity. An example of a material index is  $E/\rho$  to minimize the stiffness and density of a bar in tension, which is indicated by a line of slope 1 on modulus of elasticity versus density Ashby chart (see Figure 2 below). She also demonstrated the derivation of how one is found. From previous years, the students often wanted to understand why a slope of 1 was used for  $E/\rho$  thus this helped them understand it as well as lays a foundation for the mechanical design sequence where the students will need to derive material indices for a variety of material design-related questions. Additionally, students were given practice problems to work in pairs either during lab or after lab to practice incorporating performance indices. A sample post-lab question was:

“You must select a material for a light, stiff tie in tension with a maximum density of  $3000 \text{ kg/m}^3$  that performs as well or better than low carbon steel. The material must be a composite. What material would you select?”

The students were asked to provide the corresponding labelled Ashby chart for each question in addition to responding on the worksheet. A sample solution is shown below in Figure 2; the possible candidate materials are CFRP and aluminium/silicon carbide composite, both shown in dark red. One of the advantages of using the software with the limits or performance indices is that the materials that do not meet the criteria are greyed out providing an additional visual cue.

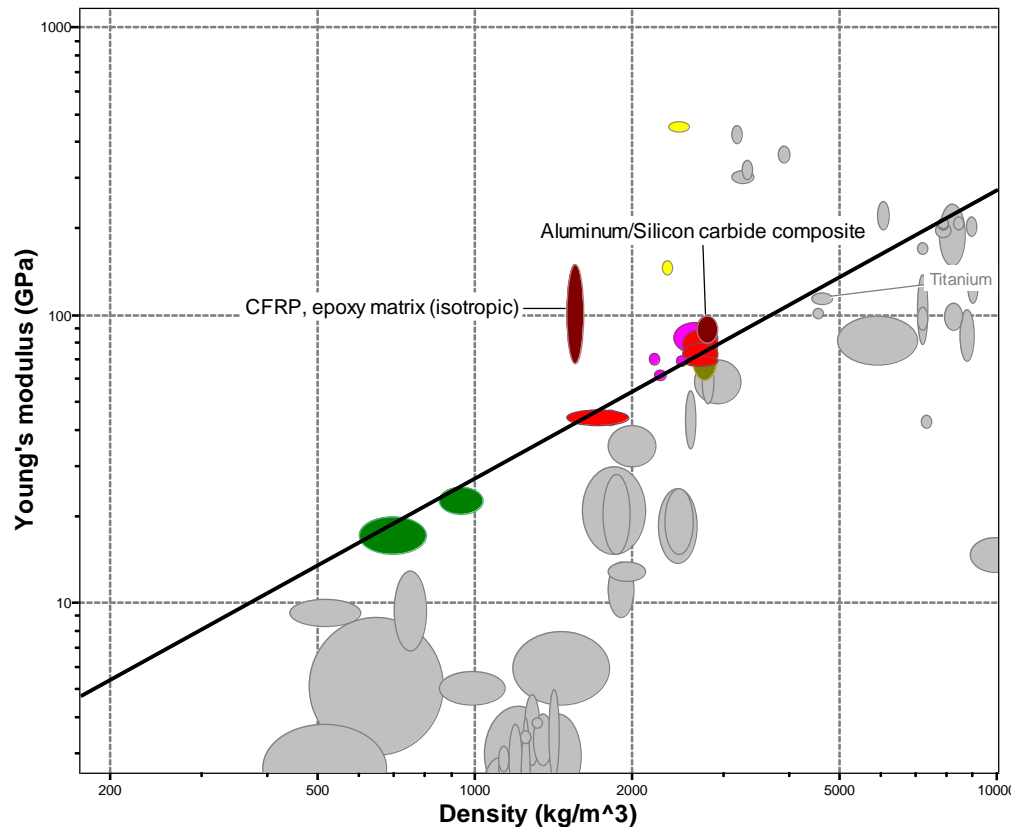


Figure 2: Ashby plot demonstrating a performance index of 1

The vast majority of student groups performed well on both materials selection labs and provided well-thought out solutions. The first lab was returned to the students prior to the second lab so that they could review it and learn from any mistakes made. There were no questions from the students in the second lab on the use of the software. All of the questions pertained to the incorporation of more constraints in the material selection process itself. The students appeared to be more engaged in the discussion during the second lab module.

The biggest deterrent of student use is that the software runs on a Windows platform. Many of the students with Macs were unable to install and run the software on their laptops. Additionally, some of the students only had desktops at home. Thus, the lab group size was determined by the number of students that were able to install the software. Though the software is available in a few locations on campus, the access to those rooms is limited to times when no classes are



present; on most days this is prior to 8:45am and after 7:30pm; thus some individuals found access to the software problematic. In upcoming offerings, the instructor will request a cart of laptops with the software installed to ensure that everyone has access to the software during lab, regardless of the type of computer they use; it is not possible to teach in the STEM computer lab as it is reserved for other courses from 8:45am-7:30pm each quarter. Additionally, this will allow all groups to be pairs instead of being limited by the number of laptops with installed software. The instructor has observed over the last two offerings that if student groups contain three instead of two participants, there is an increased likelihood of one student within the group having decreased participation.

Students were asked following each of the materials selection labs about their perception of the software. Three questions (see below) were asked using a Likert scale for strongly disagree to strongly agree (-2 to 2) in order to roughly gauge student perception. The questions were asked after the first and second materials selection lab.

Q1. I feel comfortable utilizing the software to complete materials selection based on two criteria.

Q2. I see the value in utilizing the software.

Q3. I will use this software for materials selection when I complete my capstone project.

On average, the students reported that they agreed to all three questions asked after both labs (Figure 3). There was no significant change in any question responses between the two survey times. The survey was asked to provide a qualitative insight into student perception of the utility of the software. It was anticipated that Q1 would have an average of 1 or higher after the first lab indicating the students felt comfortable with making a determination based on only two criteria.

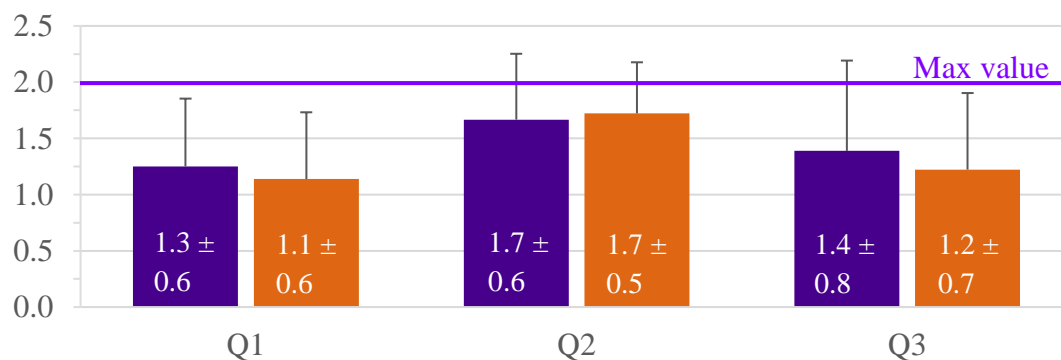


Figure 3: Perception of CES EduPack usage including mean  $\pm$  standard deviation

Their use of Ashby plots was also tested via two exam questions to identify a material or family of materials that would meet a given set of constraints to assess their understanding of the usage of the plots. The students performed well on these questions with a majority (>80%) responding correctly.

## **5. Discussion**

Understanding materials science and engineering is a beneficial skill for any mechanical engineering student. But, being able to apply the knowledge through the materials selection process is even more valuable. The first lab module served as an introductory foundation to materials selection and use of CES EduPack. By incorporating the unknown metals lab two weeks prior to the first materials selection lab module, it helped lay the groundwork for the importance and usefulness of materials selection methodology and software. The follow-on material selection lab, however, increased the student's ability to utilize the software and reason through an open-ended problem as well as introduced the idea of performance indices. The survey questions will need to be redesigned to be more specific in future offerings to provide a more useful insight into the students' perception and effectiveness of the software.

The authors are continuing to follow this cohort during Winter 2018 as they begin the mechanical systems design sequence (Juvinal & Marshek<sup>9</sup>). In machine design, the students will utilize the software to investigate possible materials to be used in the design of fasteners, shafts, gears, springs, and other components utilizing a second text (Ashby<sup>10</sup>). Further, this cohort will be followed through graduation to determine if any increase in usage occurred in the 2019 capstone projects. For the 2018 cohort, the capstone advisor has reminded the students of the availability of the software both for installation on a personal computer as well as in the project lab. All capstone student have key card access to the project lab thus reducing the software installation obstacle. The authors plan on reviewing the software at the start of the first capstone course during Winter 2019 as an intervention to reacquaint the students with the importance of material selection and usefulness of this particular software program. The software is powerful in that in the record for each material it has attributes such as durability in salt water or other fluids and environmental impact such as recyclability or CO<sub>2</sub> footprint. These properties in addition the commonly considered mechanical, thermal and conductivity requirements directly relate to the capstone project call to "design systems, components, or processes with realistic constraints such as economic, environmental, social, political, ethical, health, safety, manufacturing, sustainability." The second lab module will be modified in 2018 to create a second open-ended sustainability-related materials selection question.

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