



Leveraging student's interests in a senior design project through integration of materials selection methodology

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Finding the 'perfect' capstone project that captures the student's interest and personal passion, and incorporates the fundamental engineering knowledge they have gained over the past 3 or so years, is always challenging. As students master the fundamentals in their engineering education, the senior capstone project offers an opportunity to students to work on a problem that might have driven them to study engineering in the first place or, now armed with the new formal engineering knowledge, apply it to seeking solutions in areas of personal interest, experience and passion. The challenge here as a faculty advisor, it to work with the student to develop a viable project, which meets the educational outcomes, provides an exciting experience, and fits in the time frame. The latter, is usually unique to each institution, so keep this in mind as the scope of work covered by this example is an individual student in one semester in a 3 credit senior capstone course.

Hooking students into a capstone project through personal interests and/or experience is not a new idea and often used by others to development design problems.² Kreppel and Rabiee have stated that "often students working alone or in teams chose between these two broad areas of experience: 1) their own industrial experience through work as co-op students, entrepreneurs, service managers, trouble-shooters, etc., or 2) **their personal experience** as students, volunteers, parents, homeowners, renters, racing enthusiasts, **hobbyists, sports participants** or coaches."² They also concur on, defining the technical problems for personal projects is very challenging, however, defining a technical solution can be relatively straight forward. With respect to learning outcomes such as 'evaluating user needs and desires' and 'testing the optimal solution' lies in the feasibility based upon the adequacy of the available user input.²

Leveraging one's personal interest is shown to be effective in getting the most learning from an academic experience when 'motivation ranges on a continuum from *extrinsic* (receiving rewards such as grades, complying with rules) to *intrinsic* (satisfying personal interests, or deriving from the inherent value of an activity).³ Oh and others have shown examples on the course level that "maintaining student interest by using students' previous experiences to personalize the course material throughout the semester. When students find the course material relevant to their own interests, they are likely to become engaged and to achieve deep learning".⁴ Course projects, as reported by Oh, to "connect student learning to personal interests and to have them enjoy an "ownership" of learning and the outcomes lead to students being able to better connect their personal areas of interests to academic majors programs and daily lives."⁵

So a student says, "I want to design a new all-mountain ski, will you be my faculty advisor?." Your of reaction may be of a 'mixed bag', with thoughts on the overall scope and technical specifications of such a project, and the logistics of actually getting it done under the time constraints and in the available facilities. Based on the value of the educational experience, this question, posed by a student, can set in motion a discussion on the basic steps in the design process and defining a scope of the 15 week senior project.

This paper will show, by example, an approach to integrating design through materials selection methodology. From the advisor's perspective, the framework for working in collaboration with the student to outline a viable design project to meet all the course outcomes is presented. As

applied to a mechanical engineering student, with background in mechanics of materials, materials science, and basic laboratory techniques, a project based on the strategy of materials selection developed in the work and texts of Michael Ashby will be shown to mesh with the academic outcomes required of the senior project course itself. The student work, highlighted in the blue shaded boxes, will show the design process of an all–mountain ski. The design work and advisor insight will be discussed in parallel as the facilitation of the one-semester project for an individual student is as important as the advisor’s ability to provide guidance and assess that the course outcomes are met.

As you begin your discussion with your student, be sure they do have some ‘expertise’ in the area, e.g., lives near a ski resort and the family has skied all their lives. In that way, the student will bring not only the passion to ‘go the extra mile’ in the project, but the practical experience from years of using ski equipment. As the scope of the project is defined, the student/ advisor discussion must work to focus the project into the time frame, technical ability of the student, facilities available at the university, and most importantly, meeting the learning outcomes. Often the student has very grand ideas, which are laudable, but not practical. Without squelching any of the student’s enthusiasm, the recommended place to begin the discussion is with the fundamentals of materials selection shown in Figure 1, and with a demonstration of the tools available, primarily the CES Edupack Materials Selection software. Then, other aspects of the project, such as the cost of the materials, availability of the machine shop for fabrication, and laboratory equipment for testing, can be discussed.

Since this student has not had a formal materials selection course, the advisor can kick-start the project by acquainting the student with the strategy of materials selection and examples presented by Michael Ashby in the text, *Materials Selection in Mechanical Design*. This design-driven approach, shown in Figure 1, gives the student a tool to begin the technical evaluation of their problem, in this case, an all-mountain ski.

Strategy for Materials Selection ¹

All materials →
Translate design requirements →
Screen using constraints →
Rank using objective →
Seek supporting information →

FINAL MATERIAL CHOICE

Figure 1. ‘Ashby’s strategy’ for materials selection¹

From the point of view of the advisor, it is critical to emphasize the selection process itself, and getting the ‘buy-in’ of the student. Proper technical justification must be demanded, as well as rigorous technical support for the solutions leading to the choice of materials. Too often, students have already decided how to make the ‘product’ by only practical experience and hearsay of ‘experts’, versus letting the data drive their fabrication. The CES EduPack 2013 Materials Selection software is utilized as the primary tool to provide the technical support for the analysis, conclusions, and comments. The CES EDUPack 2013 materials selection software

used to explore several topics presented in Ashby text¹ and highlighted as follows: 1) general requirements of the materials universe; 2) use of material selection charts, 3) translation of design problems into engineering terms (or material properties tabulated in the software), 4) derivation and use the material indices, and 5) exploration of the process universe. Advanced concepts including multiple constraints and objectives, composite structure were studied with the CES software. From an advisor standpoint, the text provides a solid reference for independent learning on the student's part.

Approach to Materials Selection

Function

Constraints → translation to engineering terms

Objectives

Free variables

Figure 2. The Design Table¹

Specifically, outcomes for the senior design project course at our university state that the student must 'demonstrate the ability to identify design tasks and their objectives, apply engineering design principles either by working on a product, improving a product, or designing experiments to investigate causes of either an observed phenomenon or a problem of engineering, establish a project schedule, document the design activities, and give technical presentations of the results in the forms of progress reports, poster, final written report and oral presentations'.

This example will demonstrate the progress made to meet these requirements from, 1) the materials selection; 2) prototype fabrication, and 3) laboratory testing. This enables the student to gain a great deal of insight into ski design, as well as, the ability to 'exercise' the design process and outcomes required in the senior project.

The Project

In parallel with the advisor's comments, the student's work will demonstrate how the outcomes were achieved and the design activities were implemented in the project. The student project, "Analysis of Core Materials for Design and Fabrication of an All Mountain Ski", illustrates how the student was able to work on the materials aspect of designing his all-mountain ski.

Student work is shown in the blue boxes to give an indication of the actual project based on information reported in the poster presented at the culmination showcase event for presentation of all senior projects. The Materials Selections strategy and the 2013 CES Edupack Materials Selection software are used throughout.

Often the hardest part of a project is where to start, however, working together with much discussion and negotiation, the student was 'identified design tasks and their objectives', as show in Figure 3. The initial work with the CES software, which was used in a simple search and information mode, and a literature review, established the course of action for the entire semester.



Figure 3. The Objectives

The part of the outcome for the project that stated 'applying engineering design principles either by working on a product, improving a product', was satisfied. The 'Model', as shown in Figure 4, although simple, gave the student a starting point to apply the some basic ideas in materials selection. Here, it could be debated on the appropriateness of this model or if two models should be compared, however, the student took some design liberty and skiing experience to relate the deflection at the tip and tail of the ski to a very simple model to a complex problem.

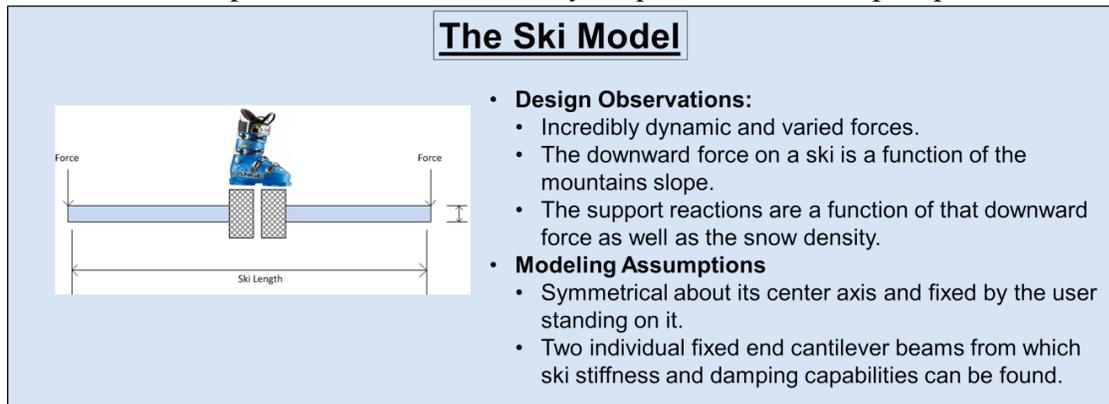


Figure 4. The Ski Model (as proposed by the student)

With a model selected, the implementation of the Ashby's Materials Selection Design Table can be applied by the student. The results for the all-mountain ski are shown in Figure 5. The CES materials selection software complements this design-driven approach and provides a visual chart of the 'Materials Universe', further stimulating the student's interest. An advisor tip here is to be sure the student follows the 'method' and does not succumb to their preconceived ideas, i.e., 'shooting from the hip' or 'my expert said....' for a material choice.

Function	Ski Core (light stiff beam)
Constraints	-Length Specified -Stiffness specified -Fracture Toughness $K > 1 \text{ ksi} \cdot \text{in}^{.5}$
Objective	-Minimize mass
Free Variables	-Cross Sectional Area -Choice of material

Assumptions for Materials Case Study
- Light Stiff Beam
- Beam Length = Ski Length
- Heavy metals and soft elastomers removed
- $K > 1$ removes brittle materials (Ceramics/Brick)

Figure 5. The Design Table: All-Mountain Ski

In the short time of this project, it is important from the advisors' standpoint that the student can work independently and take 'ownership' of the project. Here in Figure 6, the material selection charts are developed to understand the design of the all-mountain ski core material. The CES charts and software force the student to cast the application in terms of handbook properties and begin to understand the relationship between handbook properties.

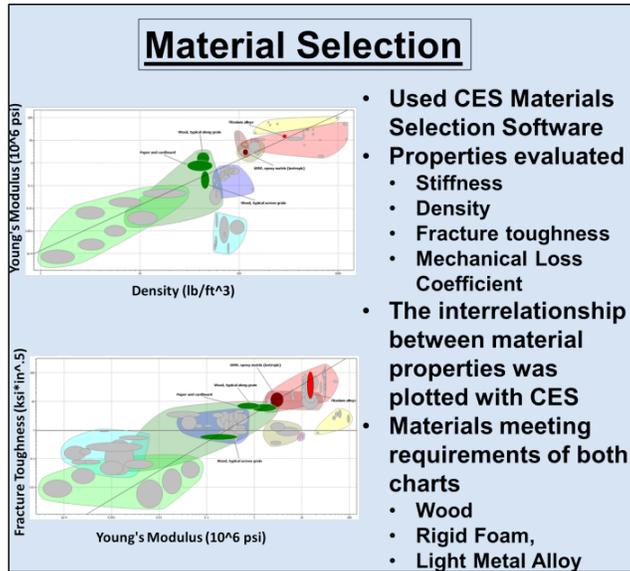


Figure 6. Basic results for CES Materials Selection Software with key charts

In Figure 7, the student exhibits the work with the Material Index, producing 'quantitative data' to compare the choices of materials, in this case, a variety of woods. This allows the student to get a deeper understanding of a more complex situation for the simple model, and supporting the findings with technical information from Materials Selection strategy. Also observed here, the student is becoming more confident with the value of the formal process of materials selection, and in their own knowledge and capabilities to apply more advanced selection techniques.

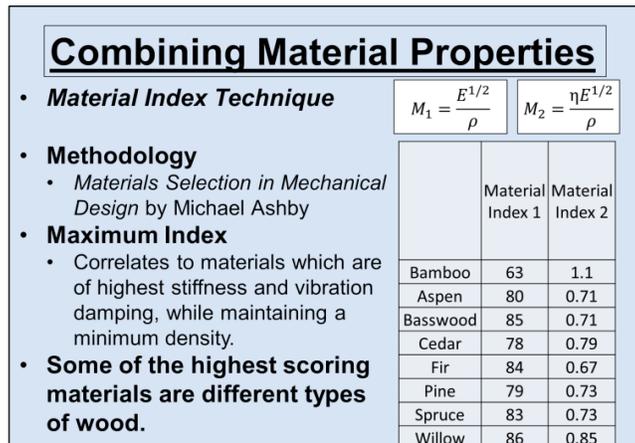


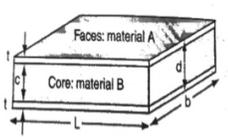
Figure 7. Data from application of Material Indices

The student, here in the Design Optimization in Figure 8, meshed information gained from the work in materials selection with a model of a composite material from the literature on ski design. Although not original or innovative, the materials selection process was advanced as the ‘rule of mixtures’ was applied to guide the design and fabrication. Options in the materials selection process allow the student explore alternatives and again make design decisions that are supported with technical information, as in this example layers composite structure.

Design Optimization

- **Material Selected → Bamboo**
 - Choice for the core material because of its high stiffness and mechanical loss coefficient.
- **The Rule of Mixtures**
 - Beam width and length held constant.
 - Volume was varied by altering the thickness of the core and fiberglass layers.
 - After calculating these values for specific points along the ski length, an optimized core profile was determined.

$$\text{Density} = \rho \sim = \frac{2t}{d} \rho_f + \left(1 - \frac{2t}{d}\right) \rho_c$$



Materials Selection in Mechanical Design
by Michael F. Ashby

$$\text{Mechanical Loss Coefficient} = \eta \sim = \frac{2t}{d} \eta_f + \left(1 - \frac{2t}{d}\right) \eta_c$$

$$\text{Bending Stiffness} = S \tilde{w} = \left[\frac{1}{12} (d^3 - c^3) E_f \right] \left\{ \frac{1}{1 + \left(\frac{B E_f t c}{2 G_c L^2} \right)} \right\}$$

Figure 8. Advanced technique applied to design of the all-mountain ski.

Armed with a model and ‘theoretical’ design data, the student now can proceed with the fabrication of the prototype, i.e., the all-mountain ski made from bamboo and covered with a fiberglass composite. The fabrication was performed by the student in the university’s machine shop. This hands-on part of the project gives the student a chance to gain experience in the shop, using their ingenuity and talents to fabricate two different prototype skis for testing. The advisor noted that the student took a great deal of pride in his work and personal satisfaction showing off the actual, full size prototypes. Additionally, this fabrication was not random, but grew out of the information gathered from the work in the materials selection phase of the project.

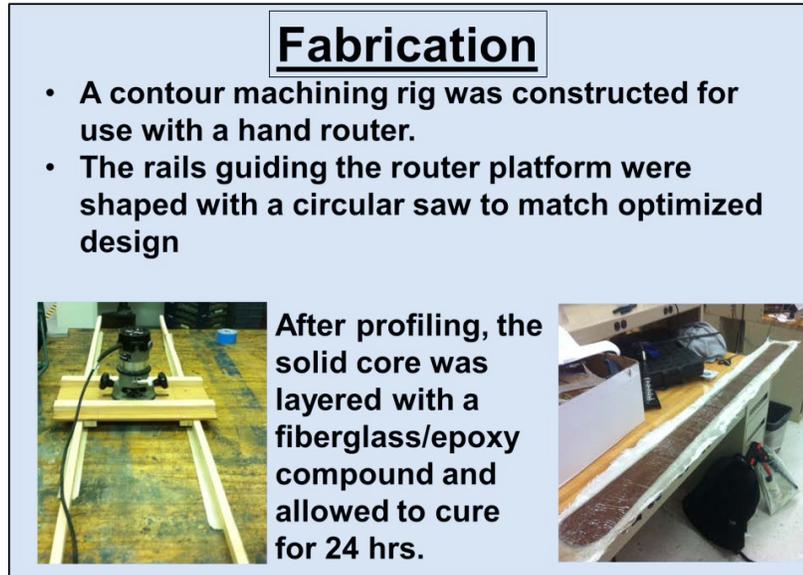


Figure 9. The Fabrication Process for Construction of the Prototype All-Mountain Skis

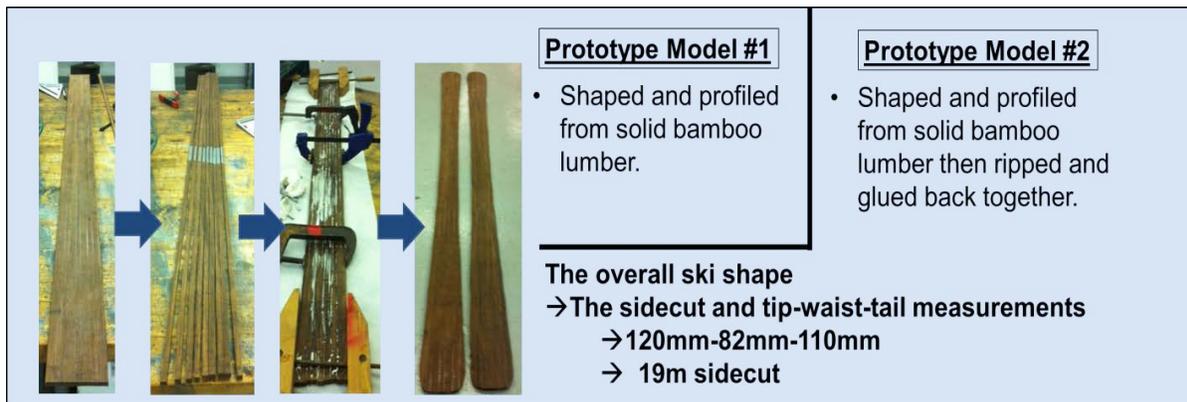


Figure 10. The Two Prototype All-Mountain Skis

To meet the learning outcome for the senior capstone project, which states “designing experiments to investigate causes of either an observed phenomenon or a problem of engineering”, the student conducted laboratory testing. Two full length skis, one with a solid core of bamboo, and the other with a ‘ripped’ core, were fabricated, as shown in Figures 9 and 10. The ‘ripped core’ has long strips of bamboo glued together, then covered with the fiberglass composite. The student selected to test the full length ski in a three point bend test for flexural strength and a vibration test. The latter test attempts to simulate the conditions experiences on the ski slope, that being the chatter of the skis against the snow and ice. The results are tabulated in in Figure 11. A first pass attempt was made to interpret the measured results and some relative comparisons were made, as shown in Figure 12. As an observation from the advisor, the short time frame of the project always cuts the data analysis short. Although the student would really like to do some more analysis, now that they are finally an ‘expert’, their impending graduation

always wins out. The project is concluded, but enough data has been gleaned to meet the course outcomes. Unfortunately, the fixed-end cantilever beam model, originally used for material selection was not tested due to the lack of time in this one semester project.

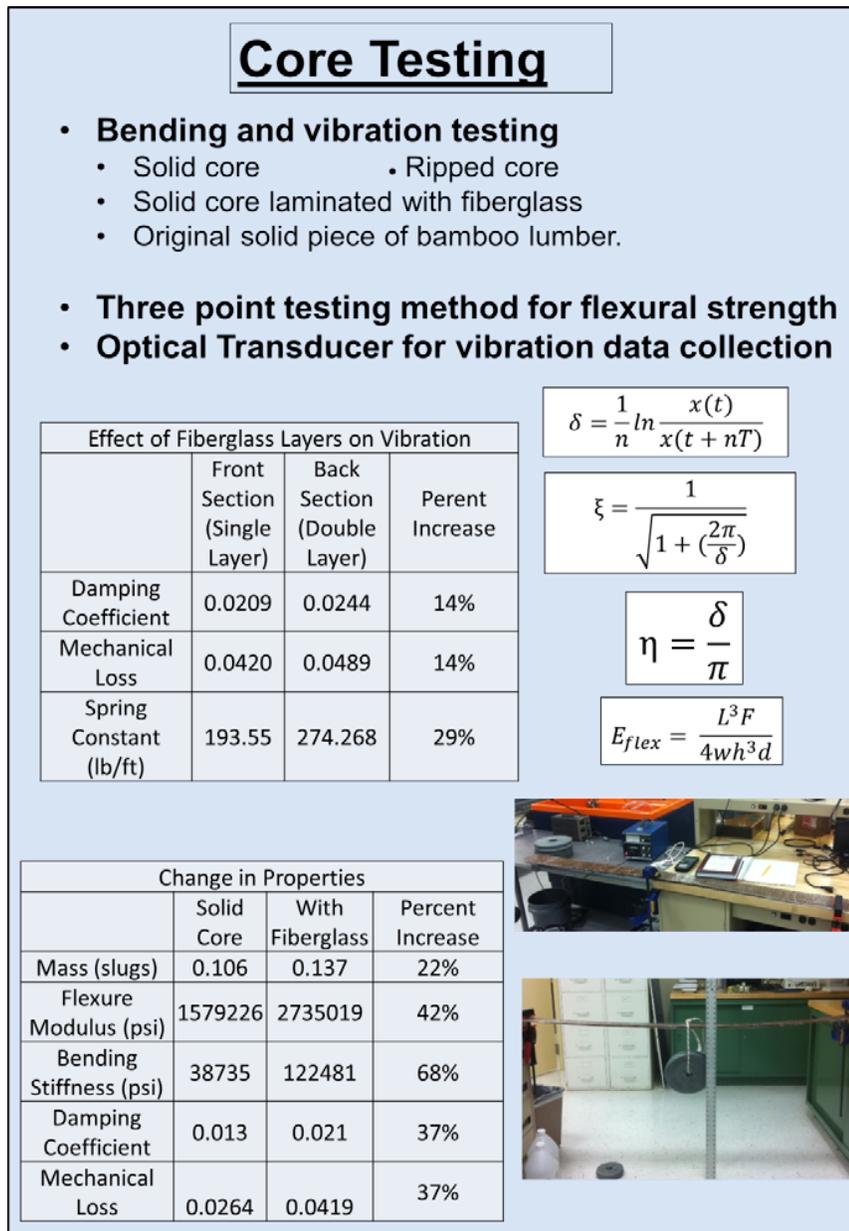


Figure 11. Measured results from Core Testing

Several conclusions were reached over the course of this project and are shown in Figure 12. Future work is outlined in Figure 13 with a focus on fabricating the ski. However, it does include additional work on materials analysis and the hybrid structures in core design. The advisor was pleased to see this was considered, because that mean the student bought in to the strategies and even the advanced methods of analysis.



Figure 12. Core design for all-mountain ski



Figure 13. Future work

The advisor observed a very strong sense of personal buy-in to this project and an ‘ownership’ of learning that took place in this project. Was a cutting edge ski design produced at the end of this project? Maybe not, however, the learning objectives were met. Upon the conclusion of this project, student reported he now had a much better understanding of the different designs of skis on the market, in particular, the high-end innovative new designs, which on review, mirrored the insights gained in this project.

‘Intrinsic motivation’ best describes the student attitude on this project. As each attended each weekly meeting throughout the semester, he was more excited about his work and the advisor’s notice he was making the connections between many engineering concepts (that had otherwise stood alone in a particular course.) As seen in Figure 14, the ‘specs’ presented for the all-mountain ski!

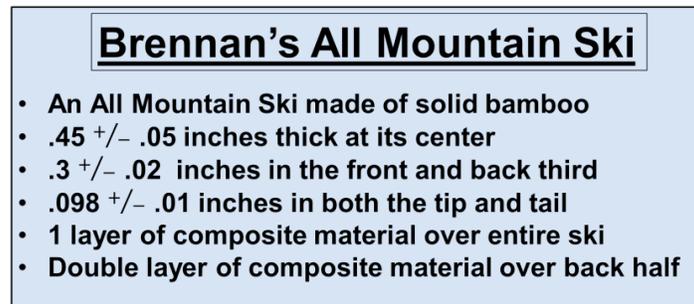


Figure 14. The proposed all-mountain ski design

In the advisors’ opinion, the example presented here, achieved the intangibles in a senior capstone project, that being, intrinsic motivation, personal ownership, and pride in the work. The use of materials selection strategies can be adapted to nearly any application or product and provides a design-driven approach and supporting technical materials. The work generated here also gave the student plenty of materials and information to meet the course outcome stating that the student must “give technical presentations of the results in the forms of progress reports, poster, final written report and oral presentations”.

The rubric for evaluation of senior design projects proposed by Wilson et al.⁶ can be a useful tool for assessment and aligns well with our particular outcomes for this one-semester capstone course. The instructor's assessment of student's work on the project discussed here and entitled, "Analysis of Core Materials for Design and Fabrication of an All Mountain Ski", is shown in Figure 15. The rubric questions in column one and selected proficiency levels in column two have been taken from the cited rubric, and these levels correspond to instructor's selection of assessment criteria, which is shown in column three.

Rubric Question	Rubric Proficiency Levels (Abbreviated) Based on Instructor's Assessment	Scale on Rubric 4-1 scale (4 as mastery) Instructor's Assessment
Identifying Functional Objectives	-addressed all objectives -key goals match design plan	4
Engineering Analysis and Methodology	-some analysis appear to be missing -the analyses that are described appear to be correct and demonstrate sound knowledge of engineering concepts.	3
Evaluation and Testing	-developed an evaluation and testing plan that assess appropriate design objectives -could be more clearly described or should be more thorough.	3
Inventiveness and Creativity	-innovative or creative thinking is evident (even if the eventual design is more traditional.)	4
Team Chemistry, Interest and Passion for the Work	-student was excited about their work and animated in their presentation of their work. (Note this was an individual project.)	4 ⁺
Written and Visual Presentation	- clearly organized, easy to read, and visually interesting.	4
Oral and Presentation and Questions	-speaks clearly, makes eye contact, and shows a solid understanding of material.	4

Figure 15. Rubric Questions for Mechanical Engineering Senior Design Project⁶

As indicated in this rubric, 'mastery' was met in five of the seven areas identified by the rubric questions and slight deficiency was noted in two other categories. On the latter, it is noted that ideally both the student (and instructor) would have liked to have more time to complete the project, that is, get that 'second try or test' in to answer questions or concerns learned in the first round of 'evaluation and testing'. However, with a 15-week project and graduation imminent, choices were made to get the 'best' results with the scope of this design project and 3-credit capstone course. So reflecting on the three parts of this project, i.e., the materials selection, fabrication and testing, the student experience incorporated previous engineering knowledge from courses, practical hands-on experience, and moved into the realm of independent life-long learning needed throughout an engineering career. The advisor also hopes this example can be used to some extent in many senior capstone projects, and as a contribution to the body of work in team projects.

Summary and Reflection by Advisor

The instructor can summarize this work as an excellent way to develop a senior capstone project around a student's personal interest, yet meet the course outcomes. The example presented here shows on the student's progress throughout the project including self-learning of materials selection methodology with CES software, key milestones for instructor/ student collaboration, and the positive impact of the project as the culmination of the student's undergraduate engineering education.

So when a student come to you and says, "I would like to design a _____, will you be my advisor?" this insight may be of value to you. You can get the conversation started, and give the student a solid, technical place to start, that connects very well with their engineering course work to this point. Listed below are points that can be transferable in 'theory and in practice' for senior capstone project.

- Design-driven approach in place and documented.
- Software easy to use with a short learning curve.
- Easily integrates / interfaces with students previous coursework
- Objectives usually focus on one specific aspect of the application or product
- Charts do simulate student interest and promote digging deeper into advanced materials selection techniques or acquiring more technical information
- Student stays focused meeting the objectives for a 15-week 3 credit senior project

Future work

Future work is to more formally track the progress in learning and the experience from start to finish of a personal choice project. This could be done from both the advisors' and students' perspectives. It might provide insight transferable into student selected projects in courses or in advising team projects, and developing clear outcomes, assessment and rubric for the capstone project. From a technical stand point, this experience in the materials selection methodology, in a project that combines the design, fabricate, and test interrelationship, can be utilized for a wide variety of applications and real world design problems.

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