Enhancing student appreciation for materials science: Integration of domain specific project-based learning in an introductory materials science course

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Siddha Pimputkar earned his B.S. in Mechanical Engineering from Illinois Institute of Technology (IIT) and Ph.D. in Materials from University of California, Santa Barbara (UCSB). He joined the Materials Science and Engineering Department at Lehigh University in 2016 as an Assistant Professor and has since been establishing a lab focused on the bulk and thin-film synthesis of single-crystal nitride materials and other electronic and optically active materials. Current material systems include cubic boron nitride, indium nitride and a variety of ternary nitride systems, including InGaN and AlInN. In addition to research, he teaches a quantum mechanics class and the introduction to material science class and enjoys exciting the next generation of students. Integrating data collection and analysis procedures to the classroom to receive quantitative feedback on the usefulness of different educational approaches is of current interest.

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Greg Skutches earned both his Master's (1997) and Ph.D. (2001) in English with a specialization in Composition and Rhetoric at Lehigh University. He joined the English Department at DeSales University in Center Valley, Pennsylvania in 1999 and returned to Lehigh in 2006 to establish and direct the Writing Across the Curriculum Program and teach courses in literature and first-year writing. In the fall of 2008, he launched the Technology, Research, and Communication (TRAC) Writing Fellows Program, which has grown into an organization of 85 discipline-based peer writing tutors who, in total, work with more than 1,300 students at Lehigh each semester. His research interests include topics in writing across the curriculum, composition theory, argument theory, and peer learning with a special focus on writing fellows programs.

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Abstract:
Materials science and engineering is often referred to as a "discovery" major, meaning that many students do not fully appreciate the breadth of materials science, nor do they understand how it relates to their chosen field of study. Students not majoring in the field are often exposed to materials knowledge in a limited number of courses, yet are often asked to apply knowledge of materials science and engineering as they work on independent or team based projects. The team elected a constructivist learning approach to test the hypothesis that student appreciation for materials science will be enhanced when working on an independent project that is intimately related to their broader career interest. In addition, the value of different mentoring approaches (peer-peer, expert-student) to the learning outcomes of the project will be examined. The course is a 106-student course that is offered to all engineering majors, and is generally composed of students from bioengineering, industrial engineering, mechanical engineering, chemical engineering and is the first course for materials science and engineering students. Students were asked to select a topic related to their professional interest. A Wiki-style article was assigned that asked students to deconstruct the life cycle of the primary material associated with the topic. Students were asked to consider ore extraction, raw material processing, product manufacturing, and end-of-life of the material, with a primary focus on the materials processing-properties-structure triad. Projects will be assessed by a team of faculty and graduate students who are not responsible for the course using a cognitive domain rubric. In addition, students will be asked to complete a survey that both addresses the cognitive domain as well as the affective domain related to the connections between concepts in materials science and their professional goals. Data will be compared across groups provided different types of mentorship during the development of their project. We will report on the final data and correlations extracted from this course to address whether project-based learning aids in enhancing student appreciation for materials science and engineering and how the utilization of different mentoring types enhances the effect.

Introduction:
Materials science is a field of study that is instrumental to large-scale problem solving in society [1-2]. The importance of the field is often apparent to students choosing to major in the field; the unique contribution of materials science principles to engineering as a whole is often less obvious to non-majors. In part, this is due to the societal tendency to champion a final product (or individual carrying out a heroic act), rather than the engineers, scientists, and technicians who made that product or feat possible. Moreover, the predisposition to associate "airplanes" with mechanical/aerospace engineering, "bridges" with civil engineering, and "medical implant" with biomedical engineering further hides from common view the contributions of materials science principles to the development of modern technology.

Many materials science courses do not adequately address this disconnect between theory and application. Materials science courses taught to non-majors tend to be lecture-style, large, and seemingly disconnected from the student's academic major. These courses can be augmented by smaller sections (e.g. recitations or study sessions), but these sections are generally focused on the problem solving approaches in materials theory, rather than application of materials to problems and products associated with the student's chosen field of study. Thus, students can complete an entire course in materials science, and walk away without a tangible understanding of why the class was part of their curriculum.

Programs such as the KEEN network [3] have sought to overcome some of these deficiencies by focusing on how technical content can be bridged with student mindset. The use of the KEEN framework (curiosity, connections, and creating value) in materials science lecture courses provide the opportunity to forge a connection between the materials triad and technology/engineering design. Furthermore, active learning can be used to illuminate how materials science drives innovation in engineering. As students will engage in problems that are closer to their own experiences, the use of a constructivist educational approach was chosen to facilitate student learning. Constructivism is an educational philosophy based on the principle that people actively construct or make their own knowledge [4-8]. Furthermore, that reality is determined by the experiences of the learner. This philosophy allows educators to take an approach to education that is active, personal, and scaffolded, also known as constructionist teaching [9]. Throughout the continuous evolution of this course, we are striving to leverage the intrinsic motivation of students (by allowing them to examine materials science through the lens of materials lifetime, which relates to sustainability) but are also designed to influence the students to develop higher-order cognitive skills by encouraging them to connect concepts in new ways [10-11].

In the current "Introduction to Materials Science" class, the faculty offered the opportunity for students to work on a project related to their chosen field of study. The project required students to select a material class (and ultimately a specific material) that is used in their academic field. The students were asked to construct a Wiki article that outlined the materials life-cycle for that material. The project incorporated active learning and scaffolded mentorship, while personalizing the assignment to ensure students were engaged from an early point. As both the mentoring approach as well as the training tools provided to students in open-ended assignments will influence the outcome of the assignment as well as student satisfaction, we partnered with the communication fellows program at our university. The TRAC ("Technology, Research, and Communication") fellows are undergraduate students selected from across the disciplines through a highly competitive application process to work as peer communication tutors in courses across the university curriculum. These students are trained in a rigorous course to prepare them to work with fellow students in all phases of the communication process. The use of TRAC fellows in this course is to enhance the student ability to communicate in ways that exhibit an understanding of the concepts beyond the "mechanics" of the course assignment.

The outcome of the project, from an educational perspective, was two-fold. First and foremost, the technical content of the project, an analysis of the materials life cycle from the perspective of the materials triad was of paramount importance. Second, the mindset of students who engaged in the project was assessed using survey tools. The faculty hypothesized that the students would be more interested in the field of materials science after engaging in a project related to their chosen field of study. In addition, we hypothesize that the use of a tiered mentoring approach, coupled with TRAC mentoring, will enhance the students overall understanding of the materials triad.

Course and Assignment Structure:

The introductory course in which these projects were implemented was taught in the fall of 2019 with an enrollment of 106 (initial, 102 final) students, all of whom attended the same lecture section (twice weekly for 50 minutes). Four recitation sections (meeting once weekly for 50 minutes) with ~ 26 students each were designed to create an active-learning environment. The student body was composed of ~ 40% Mechanical Engineering, 30% Bioengineering, 15% Industrial Engineering, 10% Materials Science, 5% Chemical Engineering, with the remaining students in other majors. Students were primarily second and third year students (50% and 40% respectively). The reasons for taking the class were numerous, including primarily the following: Prerequisite, Required of Major, Interested in Topic, and Fit my Schedule. Roughly half of the students had not really thought about materials science prior to enrolling in the course.

Each recitation section had a faculty instructor from the Materials Science & Engineering department, as well as a senior Materials Science & Engineering undergraduate student as a teaching aide. In addition, a graduate student TA was used throughout. The instructor was present during all recitation sessions where students were actively working on their Wiki assignments to answer general questions. while students could arrange to meet with the graduate TA or the main instructor outside of class. Seven TRAC fellows were provided and distributed across two of the sections. Students were provided mentorship and formative feedback from a senior expert (main class instructor) in one recitation section, a junior expert (graduate student) in another section, and the TRAC fellows in the remaining two sections. The senior and junior experts were specifically instructed to provide feedback on content only, while the TRAC fellows were limited to providing feedback on how effective the document communicated the content. A few students (~ 5) approached the senior expert and asked targeted questions to receive content feedback even though they were receiving feedback from a graduate TA or a TRAC fellow.

Students were randomly assigned to groups of four. Each student in the group of four was asked to select a material of their choosing from a traditional class of materials (metals, ceramics/glasses, polymers/elastomers, or composites/hybrids). Each group was required to cover all four materials classes. The students were tasked with becoming the group "expert" on the material of their choosing, thus allowing the team of four to learn about a material in each class in a modified "jigsaw" approach. Students prepared short (2000 word) Wiki articles related to their material, which incorporated the following information.

- Where does it come from (ore, geographically) and how is it processed?
- What is this material typically used for? Pros/ cons of this material class?
- How is it typically formed into desired shapes?
- How do humans intentionally modify the properties of the material? What properties are of interest? What is unique about the structure that leads to these properties?
- How much energy does it take to produce the material (embodied energy)?
- How is this material recycled, if at all?
- What determines the price of this material (scarcity, processing energy, ...)?

Throughout the assignment, multiple checkpoints were implemented for continuous formative feedback. Both electronic feedback as well as in person guidance was offered. Students were then graded using a rubric (Figure 1) that both addressed the research questions and communication skillset. In addition, the projects were assessed to examine student higher order learning (Figure 2). In the future, we aim to evaluate Bloom's level cognitive skills among students who have taken the Introductory Materials Course under a traditional structure and those who have been given the opportunity to learn via this type of project-based learning (Traditional Course for comparison being offered Spring 2020). This rubric was not used in grade calculations.

		Exceptional	Satisfactory	Developing	Unsatisfactory
(i)	**Material Class**: Discusses (a) important material properties of class, (b) how they contrast with other material classes, (c) Describes use of material class in society	All 3 topics discussed **in-depth** and **good examples** provided	**All 3 topics briefly** discussed with **some important aspects missing**	Only **2 topics** briefly discussed with some important aspects missing	**Less than 2** topics discussed.
(ii)	**Specific Material:** Discusses (a) general use of material, (b) important material properties, (c) origin for superior material property due to structure	All 3 topics discussed **in-depth** and **good examples** provided	**All 3 topics briefly** discussed with **some important aspects missing**	Only **2 topics** briefly discussed with some important aspects missing	**Less than 2** topics discussed.
(iii)	**Source of Raw Material:** Discusses (a) what the source material is (ore) (b) where the ore comes from geographically (c) how is the ore converted to raw material	All 3 topics discussed **in-depth** and **good examples** provided	**All 3 topics briefly** discussed with **some important aspects missing**	Only **2 topics** briefly discussed with some important aspects missing	**Less than 2** topics discussed.
(iv)	**Processing:** Discusses (a) commonly used processes to convert raw material into desired final shapes/products	Discusses 1-2 different processing routes **in-depth**	Discusses 1-2 processing mechanism in **moderate technical depth**	Mentions a process, though **lacks depth and specific** on how it works	Does not discuss a process or is **inaccurate/not relevant**
(v)	**Tailoring of Properties:** Discusses (a) what property is typically changed (b) how a property is deliberately modified (c) What changes in structure occurred to improve or modify the property	All 3 topics discussed **in-depth** and **good examples** provided	**All 3 topics briefly** discussed with **some important aspects missing**	Only **2 topics** briefly discussed with some important aspects missing	**Less than 2** topics discussed.
(vi)	**Recyclability and Sustainability:** Discusses (a) embodied energy of material (b) if/how material is recyclable (if not, why not) (c) what determines the price of material	All 3 topics discussed **in-depth** and **good examples** provided	**All 3 topics briefly** discussed with **some important aspects missing**	Only **2 topics** briefly discussed with some important aspects missing	**Less than 2** topics discussed.
(vii)	**Technical Depth**: Relevant, specific, numeric technical information and properties provided in discussion with proper units?	**Extensive** and appropriate use	**Most** discussions contain appropriate data	**Modest use** with certain discussions benefiting from their use.	**Few (1-2) to no material properties** listed and used in discussion.
(viii)	**Quality of References**: Are references from an authoritarian source and accurate/high quality?	All of them	80% of them	Less than 80%	Only a few (1-2)
(ix)	**Figures:** Relevant and informative?	All figures are	3-5 figures are	2-3 figures are	< 2 figures are
(x)	**Informative:** After reading the article I felt informed about the material and material class	Comprehensively so	Understand most topics, though more depth desired on occasion	Insufficient depth in some portions with some gaps	Incohesive discussion with numerous gaps in depth

Figure 1. Grading Rubric using for student assessment.

		Sophisticated	Competent	Not Yet Competent
(a)	**Identifies pertinent technical information about the material(s) being discussed**	All important major and minor details are identified	Some details are missing	Most major details are missing
(b)	**Identifies relevant and valid information consistent with concepts covered in course**	Details in the work are well supported by valid information sources	Sources are limited or some are questionable in nature	Sources are limited or missing
(c)	**Identifies relevant concepts associated with materials science paradigm (Process, Structure, Properties)**	All relevant concepts are identified and accurately analyzed	Some concepts are missing in the discussion	Students fail to discuss the concepts related to the materials paradigm
(d)	**Identifies relevant concepts related to the Materials Life Cycle**	All relevant concepts are identified and accurately analyzed	Some concepts are missing in the discussion	Student fails to discuss key aspects of the materials life cycle
(e)	**Identifies relevant concepts associated with broader materials science concepts (Economic, Environmental, Safety, Sustainability, etc)**	All relevant concepts are identified and accurately analyzed	Some concepts are missing in the discussion	Limited broader discussion of these concepts
(f)	**Effectively summarizes information that is reviewed.**	Information is summarized without bias and in a correct manner	Summary is limited in scope or bias is obvious	Summary is perfunctory
(g)	**Interprets information from resources collected in a correct and concise manner**	Interpretation of information indicates learning beyond facts	Interpretation is limited to facts and theories from the book	Interpretation is flawed or missing
(h)	**Effectively applies information from the course to produce a concise, correct artifact**	Information from the course is effectively tied to the information presented by the student. Appropriate language is chosen	Information from course is somewhat tied to the project. Language is partially correct.	information is disjointed from the course. Language is flawed and technically incorrect.
(i)	**Effectively uses information from the course to expand upon information in sources used.**	It is obvious that the course knowledge was used to both understand and expand upon other resources.	Course knowledge is partially used to expand upon the other resources chosen	Course knowledge is minimally included in the student artifact.
(j)	**Effectively compares and contrasts details about the materials science paradigm related to their study**	Deep understanding of Process Structure Function is apparent	Average understanding of Process Structure Function	Limited or flawed understanding of Process Structure Function
(k)	**Demonstrates an advanced understanding of the topic by using data and details to support the story.**	Data is used effectively to support the materials science paradigm	Data is used in a limited fashion	Data use is missing or incomplete
(l)	**Effectively classifies materials-related details in the hierarchy of the materials science paradigm (Processing, Structure, Function)**	Classification of specific details is correct	Classification of specific details is mostly correct	Classification is flawed or missing
(m)	**Goes beyond the technical detail and asks questions, proposes solutions based on materials science knowledge**	Projects represent more than "just the facts" and go beyond the technical details	Projects represent mostly just facts, with some further interpretation	Just the facts, and the facts may be flawed
(n)	**Proposes new solutions or strategies for use/improvement of material in the future**	Demonstrate an ability to see beyond the current state of materials and think of future strategies. The solution proposed is technically feasible and grounded in knowledge.	Some information presented that goes beyond the current state of knowledge and practice.	Only the current state of knowledge is presented.
(o)	**Communication**	Report is well organized and clearly presented. Words are chosen that precisely express the intended meaning and support user comprehension.	Some disjointed character to the student work.	Document/artifact is difficult to follow and does not follow a logical framework.
(p)	**Visual Aids**	Any figures or other visual aids used are error free and logically aid in the discussion of the material	Minimal errors in visual aids. Visual aids are somewhat effective in conveying information	Visual aids are either not used or unnecessary/ineffective

Figure 2. Rubric used to assess student learning.

In addition, students were surveyed during the course to examine their evolving interest and motivation in the field of materials science. The questions asked of the students included the motivation and mindset questions shown below, but also included demographic questions to allow for in depth data analysis. Surveys were performed exclusively during one class period using an online platform (Qualtrics) with particular attention paid to ensure ease of use on a phone-sized screen.

		Completely Disagree					Neutral					Completely Agree
(A)	I feel confident in my abilities to select a material for an engineering application.	0	1	2	3	4	5	6	7	8	9	10
(B)	I am confident in my understanding of the types of materials I can choose from to build a product.	0	1	2	3	4	5	6	7	8	9	10
(C)	I understand the fundamental differences between metals, polymers, and ceramics.	0	1	2	3	4	5	6	7	8	9	10
(D)	I believe I understand the differences between various grades of steel.	0	1	2	3	4	5	6	7	8	9	10
(E)	I believe I understand the differences between types of ceramics.	0	1	2	3	4	5	6	7	8	9	10
(F)	I believe I understand what makes different polymers unique.	0	1	2	3	4	5	6	7	8	9	10
(G)	If an assignment is difficult, I feel like I will learn a lot doing it.	0	1	2	3	4	5	6	7	8	9	10
(H)	When I have to work hard in class, I feel like I'm not as smart as my peers.	0	1	2	3	4	5	6	7	8	9	10
(I)	I believe I understand the life cycle of different types of materials.	0	1	2	3	4	5	6	7	8	9	10
(J)	I feel like I understand the materials life cycle.	0	1	2	3	4	5	6	7	8	9	10
(K)	I understand how materials science is important to engineering	0	1	2	3	4	5	6	7	8	9	10
(L)	I believe that materials are foundational to technology.	0	1	2	3	4	5	6	7	8	9	10
(M)	I believe that materials are foundational to society.	0	1	2	3	4	5	6	7	8	9	10
(N)	How materials are manufactured, used, and recycled is important to society.	0	1	2	3	4	5	6	7	8	9	10
(O)	I am excited about learning more about materials science.	0	1	2	3	4	5	6	7	8	9	10

	Select one
How many semesters have you been at Lehigh University?	1-2 3-4 5-6 7-8 9+
	Select one
Which description most closely represents your **major or concentration** at Lehigh University?	Bioengineering Chemical Engineering Civil Engineering Computer Science Computer Engineering Electrical Engineering Environmental Engineering Industrial Engineering Materials Science Mechanical Engineering
	Select all that apply
What is/are your **primary reason**(s) for taking this class?	It is a prerequisite for a class I want to take It is required for my major I thought it would be interesting It fit my schedule Other (please specify)
	Select all that apply
How much experience do you have with materials science? (click all that apply)	I took a class in high school I've seen some demos I've talked to a professor about the field It's been discussed in another class I really haven't thought about materials before.

Figure 3. Survey completed by students.

Results and Discussion:

Wiki articles were graded by an "expert" in the assigned material class (Metals, Ceramics/Glasses, Polymers/Elastomers, Composites/Hybrids). Grading was performed blind with respect to type of support the student received during the semester. The rubric shown in Figure 1 was used as the grading structure.

Grades were normalized to rater to reduce bias and grading inconsistency. This was performed under the assumption that for each grouping (grader, support) the general distribution of the class conforms to a Gaussian distribution. As such, to normalize the grader bias, all assignments were normalized to a Gaussian distribution for each grader and for each section (support): the average and standard deviation for each grader group was determined and the assigned grades normalized to the mean and difference from the mean by the standard deviation. The bias from feedback provider during the assignment was also normalized for evaluation of the final score of the assignment by taking the average of the scores (expressed in deviation from the mean in units of standard deviation) and normalizing it by the standard deviation from all students having received the same type of support.

Different student groups were provided different levels of mentorship throughout the course assignment. In Figure 4, a histogram of the grades relative to a common mean are shown in units of standard deviation for the different levels of mentorship. Overall, the TRAC and Junior expert mentorship did not show significant differences in the overall grades earned by the students. However, the access to a senior expert resulted in fewer poor performers overall, although the differences in grades between all students is relatively minor.

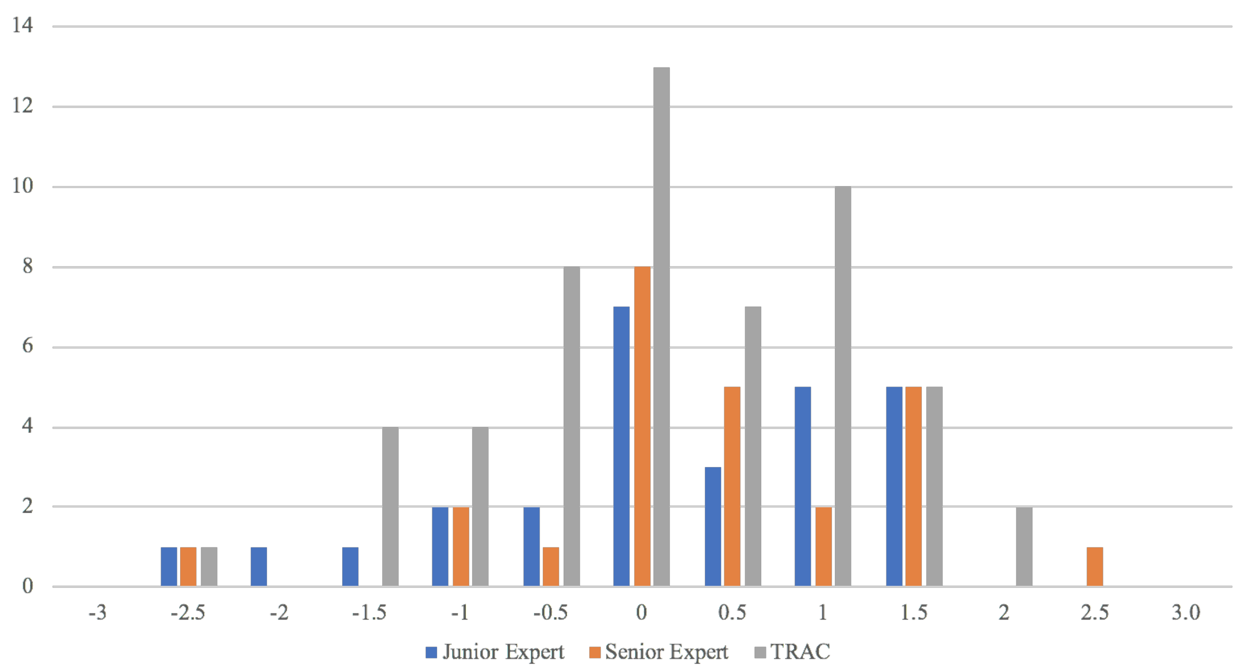

Figure 4. Distribution of grades relative to a common mean (a score of zero refers to this common mean, a value of one corresponds to one standard deviation removed from the mean based on a Gaussian distribution). Y-axis refers to number of students.

The article was assessed based on a student achievement rubric to assess higher order learning among students. This data was analyzed on the basis of tiered mentorship (Figure 5). The data indicates that the ability to connect concepts and present information in a way that exhibits a higher level understanding is enhanced when senior level mentorship is provided to the students. Surprisingly, even in areas related directly to communication skills, the TRAC fellows did not appear to be helpful in improving student learning/application of a skill to an assignment. Scores in communication, visual aids, summarization, and material interpretation are all lower in the groups who were provided a TRAC fellow for mentorship. Unfortunately, given the nature of the course, the study did not include a group that did not receive any mentorship on their project. Thus, determining whether the Junior expert and TRAC fellows were effective or ineffective mentors is difficult to extract.

Relative Scoring:
Green indicates higher competency
Red indicates lower compoentency

	Junior Expert	Senior Expert	TRAC
# Students	27	25	54
	Avg	**Avg**	**Avg**
(a)	0.03	0.26	-0.14
(b)	0.01	0.24	-0.13
(c)	0.18	0.10	-0.14
(d)	-0.20	0.16	0.02
(e)	0.01	0.37	-0.18
(f)	-0.04	0.29	-0.12
(g)	0.20	0.17	-0.19
(h)	-0.18	0.29	-0.05
(i)	0.03	0.19	-0.11
(j)	-0.10	0.38	-0.14
(k)	0.16	0.28	-0.22
(l)	-0.09	0.34	-0.12
(m)	0.08	0.04	-0.06
(n)	-0.37	0.30	0.04
(o)	-0.11	0.26	-0.07
(p)	-0.04	0.16	-0.05
Equal Weight Average	-0.03	0.24	-0.10

Figure 5. Scores on the learning rubric, relative to a common mean, as measured in units of standard deviation above or below the mean. Color scale: A green color indicates scores above the mean, a red color indicates scores below the mean. Saturation scale was set such that most saturated green occurs at +0.38, while for red it is -0.37. Questions for rows (a)-(p) correspond to questions presented in Figure 2.

Scores were also analyzed by student academic major (Figure 6). Not surprisingly, students enrolled in the Materials Science and Engineering department generally scored higher. This is the student's first course in this topic area, so prior knowledge is an unlikely cause of this observation. The faculty attribute this to student intrinsic motivation to perform well in a "home department" course as well as student interest and "buy-in" to the assignment. Majors that underperformed were the chemical engineering students, the industrial engineering students, and students who were in majors that generally do not take the course (Psychology and Architecture). The IDEAS (Integrated Degree in Engineering, Arts, and Science) students generally performed well in technical content, but underperformed in integrating knowledge. Mechanical engineering and Bioengineering students were generally average across all categories. One interesting piece of data to note is the performance of students who had not yet declared their major. We suspect that many of these students were first-year students who likely planned to major in Materials Science, thus leading us to analyze the data by student year in college (Figure 7).

Relative Scoring:
Green indicates higher competency
Red indicates lower compoentency

	Architecture	BIOE	CHE	Economics	IDEAS	ISE	MAT	MEM	Psychology	Undeclared
# Students	1	24	3	1	1	14	5	34	1	16
	Avg	**Avg**	**Avg**	**Avg**	**Avg**	**Avg**	**Avg**	**Avg**	**Avg**	**Avg**
(a)	-0.36	0.27	-0.71	-0.06	1.18	-0.40	0.46	-0.14	-1.45	0.12
(b)	-0.64	0.08	-0.64	0.64	-0.35	-0.16	0.69	-0.17	-0.84	0.31
(c)	0.20	0.00	-0.38	0.44	-0.82	-0.65	1.07	-0.04	-0.95	0.52
(d)	-0.29	0.16	-0.71	-0.85	0.85	-0.40	0.04	-0.24	-0.12	0.62
(e)	-0.34	0.11	-1.07	-0.44	0.82	-0.09	0.24	-0.27	0.35	0.43
(f)	-1.48	-0.03	-0.31	0.54	0.54	-0.33	0.80	-0.13	-1.02	0.46
(g)	-0.29	-0.11	-0.71	0.30	1.51	-0.15	0.78	-0.09	-0.69	0.24
(h)	-0.37	0.15	0.03	1.42	-1.28	-0.47	0.28	-0.14	-0.47	0.42
(i)	-0.35	0.00	-0.35	0.73	-1.36	-0.22	0.57	-0.04	-0.76	0.25
(j)	-0.34	-0.02	-1.07	-0.83	-0.83	-0.38	0.75	-0.02	-0.78	0.48
(k)	-0.20	0.16	-0.78	0.89	-0.05	-0.69	0.47	-0.04	-0.89	0.53
(l)	-0.16	-0.25	-0.16	0.78	-0.33	-0.60	0.74	0.10	-0.41	0.27
(m)	-2.55	0.24	0.00	1.03	-0.05	-1.31	1.66	-0.13	-0.82	0.60
(n)	0.43	0.47	0.43	-0.39	-0.39	-0.71	0.79	-0.32	0.54	0.37
(o)	-1.35	0.04	-0.68	1.43	0.13	-0.31	0.50	-0.18	0.10	0.49
(p)	-1.06	-0.04	-0.43	-0.70	-0.70	-0.01	0.33	-0.15	0.92	0.41
Equal Weight Average	-0.57	0.08	-0.47	0.31	-0.07	-0.43	0.64	-0.13	-0.46	0.41

Figure 6. Scores on the learning rubric, relative to a common mean, as measured in units of deviation above or below the mean. A green color indicates scores above the mean, a red color indicates scores below the mean. Saturation scale was set such that most saturated green occurs at +0.17, while for red it is -0.25. BIOE = Bioengineering, IDEAS = Integrated degree in Engineering, Art, and Science, ISE = Industrial and Systems Engineering, MAT = Materials Science and Engineering, MEM = Mechanical Engineering and Mechanics. Questions for rows (a)-(p) correspond to questions presented in Figure 2.

Relative Scoring:
Green indicates higher competency
Red indicates lower compoentency

	High School	Freshman	Sophomore	Junior	Senior
# students	6	1	61	25	7
	Avg	**Avg**	**Avg**	**Avg**	**Avg**
(a)	0.49	-0.36	-0.14	0.18	-0.16
(b)	1.16	-0.64	-0.15	0.20	-0.39
(c)	1.11	1.93	-0.09	-0.06	-0.12
(d)	0.95	0.96	-0.12	0.08	-0.52
(e)	0.63	1.86	-0.07	-0.20	0.21
(f)	0.97	-0.31	-0.08	-0.01	-0.19
(g)	0.66	-0.29	-0.12	0.13	-0.15
(h)	0.79	-0.37	-0.13	0.11	0.10
(i)	0.93	-0.35	-0.09	0.04	-0.14
(j)	1.10	-0.34	-0.15	0.04	0.13
(k)	1.15	-0.20	-0.09	0.04	-0.21
(l)	0.79	-0.16	-0.11	-0.11	0.22
(m)	1.61	0.00	-0.22	0.25	-0.59
(n)	1.22	-2.35	-0.13	0.17	0.05
(o)	0.94	-0.35	-0.12	0.21	-0.60
(p)	0.80	-0.11	-0.06	0.05	-0.45
Equal Weight Average	0.96	-0.07	-0.12	0.07	-0.18

Figure 7. Scores on the learning rubric, relative to a common mean, as measured in units of deviation above or below the mean. A green color indicates scores above the mean, a red color indicates scores below the mean. Saturation scale was set such that most saturated green occurs at +0.19, while for red it is -0.23. Questions for rows (a)-(p) correspond to questions presented in Figure 2.

The class was composed primarily of junior and senior students. There was a small fraction of students who were in the senior class or first-year class. In addition, partnerships with local high schools sometimes brings high school students into the introductory classes at our university. High school students, surprisingly, scored significantly higher on the learning outcomes over the other classes assessed. As scores were given without knowledge of the student class, major, or year, this is a very surprising piece of data. There is the potential for student achievement disparities, in that high school students taking courses in college are generally high-achieving students. While our institution is a highly selective university, we still have a broad distribution of student preparation coming into our classrooms. This data does indicate, however, that age and college course experience does not limit student achievement in learning outcomes that relate to concept connections, integration of information, and the use of sources to solidify arguments. Another notable observation is in the continuous improvement of students (college-level) from sophomore year to junior year; indicating that perhaps the junior year is the best year to take a course for non-majors. The data related to the senior class represents a relatively small sample size; seniors taking this course would be non-major students and likely not invested from the beginning.

In addition to student grades, the faculty wanted to assess how student interest and motivation evolved during the course. A survey was constructed to evaluate student interest level, student cognitive understanding of key material concepts, student learning style, and student general beliefs about materials science. Students were asked to complete the same electronic survey at three points throughout the course (first week of class, before the mid-term, last week of class); the instructor used the feedback from the survey to adjust the course pace and content as necessary. Generally, students were interested in the course at the beginning. The understanding of different materials concepts was rated as below average at the beginning, as expected. Overall students seemed to believe that materials are critical to mankind.

As the course evolved, student confidence in topics increased, which indicates that the course was enhancing cognitive knowledge of materials science. The level of self motivation generally did not shift; these questions speak to student perceptions and tendencies towards academic work. Student perception of the importance of materials science remained high throughout the class. Unfortunately, student interest waned over the course of the class. The surveys were distributed at times consistent with course examinations; student burnout may be implicated in part. In addition, student response rate declined by 50% over the semester, which likely skewed the results.

Normalized (Precent of class, entire class)

Line represents average

	MAT 33 F19	0 Completely Disagree	1	2	3	4	5 **Neutral**	6	7	8	9	10 Completely Agree	Avg	Stdev	Total Count
I feel confident in my **abilities to select a material** for an engineering application.	Beginning	3	10	17	22	8	6	15	11	5	1	0	4.0	2.3	98
	Middle	3	1	5	13	8	14	17	26	8	3	1	5.4	2.1	76
	End	4	4	6	4	2	6	24	22	17	13	0	6.1	2.4	54
I am confident in my understanding of the **types of materials** I can choose from to build a product.	Beginning	6	12	20	20	8	11	12	6	3	0	0	3.4	2.1	98
	Middle	3	1	5	8	5	13	2[illegible]	18	14	8	4	6.0	2.3	76
	End	4	4	6	0	4	11	17	11	30	11	4	6.4	2.5	54
I understand the **fundamental differences between metals, polymers, and ceramics.**	Beginning	1	6	7	13	7	16	17	16	8	5	2	5.2	2.3	98
	Middle	1	0	1	4	1	5	13	24	17	20	13	7.4	2.0	76
	End	2	2	2	2	0	4	9	13	19	26	22	7.8	2.3	54
I believe I understand the differences between various **grades of steel**.	Beginning	19	14	19	16	7	11	6	4	1	1	0	2.7	2.2	98
	Middle	9	4	11	7	13	13	16	17	9	1	0	4.6	2.5	76
	End	2	4	7	7	4	15	[illegible]7	17	15	11	2	5.8	2.4	54
I believe I understand the differences between **types of ceramics**.	Beginning	21	11	26	21	4	9	6	0	1	0	0	2.3	1.8	98
	Middle	5	4	13	13	13	18	11	8	5	5	4	4.6	2.5	76
	End	4	2	7	4	6	22	[illegible]5	17	11	7	6	5.8	2.4	54
I believe I understand what makes **different polymers** unique.	Beginning	15	13	21	19	11	9	4	2	1	2	1	2.8	2.2	98
	Middle	4	3	7	4	9	7	14	17	17	13	5	6.1	2.6	76
	End	4	6	2	4	4	17	15	17	17	9	7	6.1	2.5	54
If an **assignment is difficult**, I feel like I will learn a lot doing it.	Beginning	2	3	3	6	6	17	1[illegible]	22	15	4	6	6.0	2.3	98
	Middle	8	5	8	11	9	[illegible]2	16	13	12	5	1	4.9	2.6	76
	End	7	7	6	6	4	15	19	13	9	7	7	5.4	2.9	54
When I have to **work hard** in class, I feel like I'm not as smart as my peers.	Beginning	5	5	16	19	7	12	8	13	4	5	4	4.5	2.6	98
	Middle	5	1	9	5	9	21	11	11	14	3	11	5.6	2.7	76
	End	9	2	9	11	4	19	11	9	11	6	9	5.2	2.9	54
I believe I understand the **life cycle of different types of materials**.	Beginning	10	13	14	24	8	13	12	3	1	0	0	3.2	2.0	98
	Middle	7	1	8	7	12	[illegible]5	12	21	4	3	1	5.0	2.2	76
	End	4	6	2	0	9	7	2[illegible]	19	15	11	2	6.1	2.4	54
I feel like I understand the **materials life cycle**.	Beginning	7	13	18	22	10	15	9	3	1	0	0	3.2	1.9	98
	Middle	7	3	5	5	5	21	18	26	5	1	3	5.3	2.3	76
	End	4	4	4	2	6	13	11	24	20	13	0	6.2	2.4	54
I understand how materials science is **important to engineering**	Beginning	0	1	2	2	3	3	11	13	[illegible]1	14	29	7.8	2.1	98
	Middle	1	0	1	3	1	3	7	14	17	17	36	8.2	2.1	76
	End	2	0	2	2	0	4	4	9	15	20	43	8.4	2.1	54
I believe that materials are **foundational to technology.**	Beginning	0	1	0	0	0	4	6	15	29	17	28	8.3	1.6	98
	Middle	0	0	3	0	0	5	11	18	22	14	26	8.0	1.8	76
	End	0	2	0	0	0	6	9	11	15	22	35	8.3	1.8	54
I believe that materials are **foundational to society.**	Beginning	0	1	0	2	3	1	7	17	2[illegible]	17	28	8.1	1.8	98
	Middle	0	0	0	0	3	4	4	14	34	8	33	8.3	1.5	76
	End	4	2	0	0	0	6	2	9	19	17	43	8.3	2.4	54
How materials are manufactured, used, and recycled is **important to society.**	Beginning	1	2	2	2	5	2	5	7	17	16	40	8.1	2.4	98
	Middle	0	0	5	1	1	3	8	14	17	13	37	8.1	2.2	76
	End	4	2	0	0	0	6	9	9	11	13	46	8.2	2.5	54
I am **excited about learning more** about materials science.	Beginning	2	0	0	2	4	3	10	16	18	19	24	7.8	2.1	98
	Middle	8	4	1	5	8	7	16	16	13	11	12	6.1	2.9	76
	End	11	4	2	6	7	17	11	13	11	9	9	5.6	3.0	54

Figure 8. Student survey responses. Green saturation maps are separately normalized to each row.

	1-2 semesters			3-4 semesters			5-6 semesters			7-8 semesters		
# responses	50	24	11	38	39	35	7	11	5	3	2	1
	Beginning	Middle	End	Beginning	Middle	End	Beginning	Middle	End	Beginning	Middle	End
	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg
(A)	0.16	0.08	0.25	-0.09	-0.04	0.15	-0.39	-0.06	-1.71	-0.63	0.08	1.89
(B)	0.32	-0.04	0.54	-0.28	0.09	0.17	-1.15	-0.14	-2.17	0.89	-0.46	1.63
(C)	0.28	0.17	0.11	0.01	-0.04	0.18	-1.92	-0.37	-1.60	-0.20	0.63	2.20
(D)	0.01	-0.05	0.53	0.25	0.01	0.20	-0.98	-0.09	-2.83	-1.03	0.87	1.17
(E)	0.14	-0.24	0.59	-0.02	-0.18	0.08	-0.62	1.02	-1.98	-0.67	0.88	4.22
(F)	0.49	0.05	0.94	-0.44	-0.02	-0.12	-0.81	0.06	-1.75	-0.81	-0.62	-0.15
(G)	0.16	0.13	1.14	0.08	0.37	0.02	-1.02	-1.18	-1.81	-1.35	-2.41	-1.41
(H)	-0.13	0.03	-0.42	0.14	-0.28	-0.21	0.82	0.23	1.16	-1.47	3.91	0.76
(I)	0.27	-0.09	0.49	-0.17	0.09	0.06	-0.89	0.04	-1.46	-0.17	-0.96	-0.06
(J)	0.23	0.20	0.36	-0.19	-0.07	0.10	-0.34	-0.48	-1.59	-0.53	1.70	1.81
(K)	0.17	0.72	-0.06	0.36	-0.26	0.29	-1.99	-0.52	-1.63	-2.85	-0.66	0.57
(L)	0.14	0.37	0.03	0.19	0.12	0.18	-1.26	-0.78	-0.53	-1.92	-2.46	-0.33
(M)	0.28	0.21	0.16	0.21	-0.01	0.13	-2.08	-0.02	-1.10	-2.41	-2.29	1.70
(N)	0.17	-0.01	0.09	0.40	0.41	0.10	-1.64	-1.05	-0.99	-4.07	-2.05	0.81
(O)	-0.14	0.44	0.95	0.70	0.28	0.41	-1.80	-1.74	-4.39	-2.46	-1.11	-2.59

Figure 9. Student survey responses by year. Questions for rows (A)-(O) correspond to questions presented in Figure 3.

The surveys were also broken down by academic major and class year. Interestingly, first and second year students did not undergo a significant shift in their perceptions of their abilities or in their perceptions of the importance of materials science to society. However, the more advanced the student, the more the class impacted their survey responses. Students in their 3rd year (5-6 semesters at university) generally showed a decrease in their perceptions, while more senior students exhibited an increase. This is indirectly correlated to the learning scores received by students. The explanation for this is unclear; the data is likely skewed by a reduction in the response rate, however, there are likely more factors at play.

Student perceptions are also related to their academic major. Chemical engineering students exhibited the most pronounced change in their perceptions of materials and understanding of materials classes. The materials lifetime analysis may have appealed to their interest and knowledge in process design. There are no apparent trends among mechanical engineering, bioengineering, or materials science students.

	MEM			BIOE			ISE			MAT			CHE		
# responses	41	32	25	30	20	15	14	12	5	8	8	5	4	3	2
	Beginning	Middle	End	Beginning	Middle	End	Beginning	Middle	End	Beginning	Middle	End	Beginning	Middle	End
	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg
(A)	0.43	0.02	0.13	-0.03	0.38	0.22	-0.96	-0.84	-0.91	-1.08	-0.42	-1.11	0.79	1.58	2.39
(B)	0.27	-0.05	0.35	-0.14	0.44	0.10	-0.58	-1.04	-1.57	-0.31	-0.46	-0.57	0.31	2.04	1.63
(C)	0.45	0.10	0.20	-0.14	0.43	0.20	-1.35	-0.95	-0.80	0.17	-0.99	-1.00	0.55	1.63	1.20
(D)	0.99	0.21	0.25	-0.39	0.22	-0.23	-1.12	-1.38	-1.23	-1.94	0.12	-0.03	0.56	0.70	1.67
(E)	0.44	-0.59	0.26	-0.07	0.48	0.16	-0.69	-0.45	-0.98	-1.21	0.38	-1.18	0.91	3.05	2.72
(F)	0.29	0.10	0.25	0.09	0.58	-0.41	-1.02	-1.95	-0.35	-0.18	0.13	-0.95	0.44	1.55	1.85
(G)	0.10	0.03	-0.13	-0.32	-0.01	0.53	-0.88	-1.24	-1.21	1.73	1.22	0.19	0.98	0.43	1.59
(H)	0.07	0.13	0.32	-0.60	-0.89	-0.31	0.82	0.49	0.56	0.91	0.28	-3.24	-0.22	2.07	2.26
(I)	0.44	0.38	0.26	-0.37	-0.21	-0.26	-0.74	-1.54	-0.46	-0.17	0.29	-0.66	0.83	2.37	1.44
(J)	0.32	0.45	0.37	0.04	-0.20	-0.32	-0.69	-1.47	-0.59	-0.82	-0.18	-0.79	0.06	2.36	1.81
(K)	0.35	0.37	0.21	-0.05	-0.01	-0.43	-1.13	-1.99	-0.83	0.78	0.97	1.37	0.15	0.84	0.07
(L)	0.33	0.20	-0.01	-0.12	0.04	0.00	-1.11	-1.46	-0.73	0.87	0.79	1.47	-0.26	1.04	0.17
(M)	0.14	0.18	0.34	0.09	0.16	-0.23	-1.22	-1.04	-0.10	1.17	0.34	-0.50	0.17	0.04	0.20
(N)	0.00	0.29	0.05	0.70	-0.20	-0.12	-1.64	-1.22	0.81	1.43	0.82	-0.59	-2.32	0.28	-0.19
(O)	-0.09	-0.01	-0.07	0.57	0.29	0.34	-2.22	-2.36	-2.79	1.70	2.02	1.41	0.95	1.56	1.91

Figure 10. Student survey responses by major. MEM = Mechanical Engineering and Mechanics, BIOE = Bioengineering, ISE = Industrial & Systems Engineering, MAT = Materials Science & Engineering, CHE = Chemical Engineering. Questions for rows (A)-(O) correspond to questions presented in Figure 3.

Future Work:

Wiki articles provide a repository of information for future students enrolled in the class. The opportunity to contribute to a growing archival database is generally a motivating factor for projects, as the assignment is perceived as "more real". To accommodate this type of coursework and archive, the Department of Materials Science and Engineering has established a department server to house archived student work. In future permutations of the course, these active learning assignments will continue to evolve to best encourage students to both understand and appreciate the value of materials science and engineering. We will evolve to use tiered mentorship in both project-based learning sections of this course as well as more traditional sections. In a future study, we will compare student perception and student cognitive understanding of the materials paradigm as a result of taking a different style of course.

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