Research on Use of Cambridge Engineering Selector (CES4) Software in an Introductory Materials Science Course

Chrysanthe Demetry
Worcester Polytechnic Institute

I. Introduction

Cambridge Engineering Selector (CES4) software[1] is being used in both educational and professional settings as a tool for design and material selection. Using educational versions of the software, students are able to browse a database of material attributes, learn about and compare different materials in a graphical manner, and select materials using a variety of design criteria. Integration of the software into both elementary and advanced courses has been reported to engage student interest and increase course enrollments.[2] After becoming familiar with the functionality of the software, and with some knowledge of psychological type theory, I wondered whether CES4 would appeal especially to student learning styles that are sometimes underserved by the traditional approach to introducing materials science. One would expect that particular learning styles would be better served by an initial introduction to tangible applications than to the more abstract topics of material structure, and by the exploratory, non-linear approach to learning that the software offers. To date, however, it seems that no formal studies have been conducted to investigate how students interact with the software and whether it appeals to some more than others.

In this research I explore student response to and utilization of CES4 software and test hypotheses about how it might be received by students with different learning styles. In a recent offering of a large enrollment introductory course, students were provided with the most basic version (Edu Level 1-2) to augment a traditional textbook. While the content and general approach of the course remained the same as previous offerings, assignments were modified to include questions that drew on CES4 in some way. In addition, students were encouraged to use the software as a resource for an optional course project. Concurrently, students' learning styles were measured using the Myers Briggs Type Indicator (MBTI), and questionnaires were administered to probe the extent to which they used CES4 and their attitudes toward it. These results were analyzed to determine whether use of the software appeals to students who may otherwise struggle with the course because of their learning style.

II. Background on Psychological Type and Learning Styles

Many learning style models have been used successfully to predict or explain differences in student response to subject matter and to teaching and learning environments.[3,4] One of the more commonly used instruments with an extensive research base is the Myers-Briggs Type Indicator (MBTI), which is based on Jungian theory of psychological type. Only a brief summary of type theory will be given here; interested readers are referred to several articles and books for additional details and explanation.[5-8]

According to Jungian theory, while individuals can typically operate in multiple environments and call upon a variety of skills, each of us has intrinsic preferences or tendencies— ways in which we feel most comfortable when we seek information and make decisions. Furthermore, rather than being random, there are patterns or classifications that are useful in describing the vast range of human behavior. The MBTI groups these patterns into four dimensions, with two possibilities in each dimension. Table 1 summarizes the four dimensions and provides some concrete examples of how they manifest in learning preferences.

Over the past several decades, many studies have shown that some MBTI types tend to struggle in or drop out of engineering programs more than others. These findings are most often explained by mismatches between traditional teaching styles and the learning preferences of many of our students. In general, traditional engineering education is biased towards Introversion (I) over Extraversion (E), Intuition (N) over Sensing (S), Thinking (T) more than Feeling (F), and Judgment (J) over Perception (P).[4,6,9] The S-N dimension is particularly influential on learning, and there is a common mismatch between teachers and students in this area.[7,10] The majority of engineering faculty tend to be I<u>n</u>tuitors, focusing on theory, concepts and principles, while more students tend to be <u>S</u>ensors, perceiving information more readily from practical experience and observation of concrete events. TJ types—methodical, logical, organized— are likely to be attracted and retained well in engineering education, while we are more likely to lose those with F and P preferences— those who tend to weigh human, subjective factors first and those who prefer to be flexible and spontaneous.[4,6,9]

Rather than being overwhelmed by the notion of providing an ideal learning environment for all 16 possible types, teachers have been advised to use a balanced approach and a breadth of strategies that appeal to each preference at least some of the time.[3] Furthermore, type-conscious instructors will recognize that students are also well served by developing modes of learning that come less naturally to them. Often, achieving this balance and breadth can be easier said than done, even with a knowledge of one's own type and openness to a variety of teaching strategies.

III. Possible Type-Dependent Responses to Introductory Materials: Could CES4 Software Make a Difference?

Traditionally, introductory materials science courses begin with an examination of the atomic, molecular, and crystalline structures of materials, to provide a foundation for understanding variation in material properties among metals, ceramics, and polymers. This somewhat abstract approach is likely to resonate more with I<u>n</u>tuitors than <u>S</u>ensors. It is also possible that <u>I</u>ntroverts may be more naturally drawn to the inner workings of materials, whereas <u>E</u>xtraverts look outward to products and objects. Recently, new editions of textbooks have tended to integrate properties and applications (S,E) into discussions of structure, and to include consideration of environmental implications when using particular materials (F). Note that all of these trends address type preferences that have traditionally been underserved in engineering education (E,S,F). Helping P students may be most challenging; past research in my Introduction to

Table 1: Examples of Learning Preferences Associated with Dimensions of MBTI Type*	
A person's interest flows mainly to, or energy is derived from…	
the outer world of actions, objects, and persons	the inner world of concepts and ideas
• Talking, discussion • Action, psychomotor activity • Working with a group	• Reading, verbal reasoning • Time for reflection and internal processing • Working individually
Extraversion: **E**	Introversion: **I**
Preferences for perception (awareness, taking in information) lean toward…	
Immediate, real, practical facts of experience	Possibilities, relationships, meanings of experience
• Going step-by-step • Tasks calling for observing specifics, recall of facts • Practical interests	• Finding own way in new material • Tasks calling for grasping general concepts • Intellectual interests
Sensing: **S**	Intuition: **N**
A person prefers to make judgments or decisions…	
Objectively, impersonally	Subjectively and personally
• Logical organization • Objective material to study • Depth and accuracy of content	• Personal rapport with teacher • Learning through personal relationships • Personal connection to content.
Thinking: **T**	Feeling: **F**
A person prefers mostly to live…	
in a decisive, planned way, aiming to regulate and control events	in a spontaneous, flexible way, aiming to understand life and adapt to it
• Work in a steady, orderly way • Formalized instruction • Prescribed tasks	• Work in a flexible way, follow impulses • Informal problem solving • Discovery tasks
Judgment: **J**	Perception: **P**

* Adapted from G. Lawrence, *People Types & Tiger Stripes*, 3rd Ed. Center for Applications of Psychological Type, Inc., Gainesville, FL: 1993, pp. 13, 40, 41.

Materials Science course showed that students with a Perception orientation struggled compared to those with a Judgment orientation,[11] perhaps reflecting its relatively structured, organized approach deemed necessary for smooth functioning given its large enrollment.

After becoming familiar with the functionality of the CES4 software, it seemed to me that it had the potential to provide a supportive learning environment for students with a preference for Perception, as well as for students with other underserved learning styles. The educational version (Level 1-2) of the CES4 software provides records for 67 commonly used materials. Each record begins with a general description of the material, and shows a familiar product that is made from that material. I expected that the immediate reference to a tangible product, and a visual representation of the product, would appeal to Sensing students. Each record also has a tabulation of material properties, explanations of design considerations and typical uses, and links to references, possible material processes, and producers of the material. Using a tree-like structure based on material classes, students can *Browse* to explore records of interest. The discovery- and impulse-orientation of the Browse feature may appeal to Perceiving students, and certainly provides a more flexible and responsive learning tool than a traditional textbook. There is also a *Search* function that allows one to find materials that might be used to make a particular product (e.g., bicycle helmets), or to investigate a material with a particular tradename (e.g., "Lexan"). Again, I expected that the ability to connect with familiar products and applications would appeal particularly to Sensors and perhaps to Extroverts as well. Finally, there is a *Select* function where one can use a graphical approach, tree-based selection, or material property limits to identify materials that meet particular criteria. It is possible that the *Select* activity would appeal especially to Sensors (using criteria, eliminating materials step-by-step) and Judgers (making decisions, narrowing options in an ordered way).

IV. Research Design

A classroom research study was conducted to test the informal hypotheses about student reactions to CES4 software described above. Here I first describe the course and how Cambridge Engineering Software (CES4) was used, and then methods that were employed to characterize student response and learning styles.

The software was used in a Fall 2004 offering of Introduction to Materials Science, which at Worcester Polytechnic Institute (WPI) is taught in a seven-week format with four 50-minute lectures and one conference section meeting each week. As is typical for the course, the group of students was large (90) and quite diverse, from sophomores to seniors and from a variety of engineering and science majors, with some taking the course as a requirement and some as an elective. Class periods are "active lectures," in which 5-10 minute mini-lectures are interspersed with individual or small-group problem solving, often utilizing classroom feedback technology (CPS).[11,12] There are a variety of evaluation methods including on-line "preparation assessments" to promote reading prior to class, in-class problems, homework assignments, and three exams. In addition, students had the option of doing a material selection project on a topic of interest, reducing some of the weight on exams.

It is important to emphasize that the CES4 software was used as a supplement to a traditional textbook (W.D. Callister, Jr., *Fundamentals of Materials Science and Engineering: An Integrated Approach)*.[13] Moreover, the course objectives focused on the science of material structure and properties rather than design and material/process selection. The full functionality of the software would best be utilized in upper-level design courses (e.g., see Reference 14). Nevertheless, I felt that using the software, even on a limited basis and for simplified problems, could provide more motivation for the study of the structure of materials and show how material selection would enter into a variety of engineering disciplines.

Table 2: Examples of Homework Questions Drawing Upon CES4
IDENTIFYING TRENDS IN PROPERTIES BETWEEN AND WITHIN MATERIAL CLASSES A. Using Graph Stage under Select in CES4, make a bar chart showing Maximum Service Temperature of all the materials in its Level 1 database. Identify some of the materials on the plot, especially at the extremes. What can you say, in general, about the relative maximum service temperatures of metals, ceramics, and plastics? How does this relate to interatomic bonding? B. Make a bar chart of the tensile strengths of all of the thermoplastics in the CES4 database. Label all of the materials for which the mer structures are shown in Table 4.3 of your textbook, and turn in the chart with your writeup. Based on your knowledge of how chemistry and structure of polymers influence strength, make the following direct comparisons and provide a reasonable explanation for why one is stronger than the other. If there is a lot of overlap, then discuss the various structural factors that could be playing a role. a) PTFE vs. PVC; b) PP vs. PS; c) PE vs. acetal; d) PE vs. PC.
EXPLORING COMMON MATERIALS AND THEIR APPLICATIONS C. Consider the following four commonly used materials: a) Polyethylene (C_2H_4); b) Boron carbide (B_4C); c) Aluminum oxide (also called Alumina) (Al_2O_3); d) Magnesium (Mg). Look up each material's record in the CES4 database (use Level 2). What material class is it in? Describe something about the material that you found interesting from its record (typical uses, properties, etc.)
MATERIAL SELECTION D. You are in charge of selecting an appropriate metal for a cylindrical rod that will be loaded in tension. The rod must be 380 mm long with a diameter of 10.0 mm. *The rod should experience neither plastic deformation nor an elongation of more than 0.9 mm when the applied tensile force is 24,500 N.* a) Which of the metals in the CES4 database would meet these requirements? b) Of those candidates, which shows the best combination of low cost and low weight? To support your conclusion, show a plot of material cost and density for the candidate materials. (Include the plot with your assignment, and make sure to show/explain how you arrived at limits for mechanical properties.) c) For the material you chose, how much would the rod weigh? E. You are asked to select an elastomer that would be suitable for use as a gasket in a pump for liquid CO_2 at -75°C. A gasket creates a seal between two mating surfaces; it must be resilient (compressible) in order to create that seal. a) What thermal property of polymers is relevant for the resiliency requirement? Explain. b) Use CES4 to identify which elastomers would be candidates for this application.

A 100-seat license was purchased that allowed the software to be distributed to each student for installation on his or her personal computer. Because the software was being used on an experimental basis, I elected to supply the software to the students free of charge. (The cost of the license was approximately $20 per student.) One conference section early in the term was used to demonstrate the functionality of the software and show examples of how it could be used to explore material properties and as a tool for material selection decisions.

Almost all of the eight homework assignments, typically with one or two out of five questions in each, drew upon CES4 in some way. Several examples of questions are shown in Table 2. Some, like items A and B, were used to reveal or reinforce trends in material properties that students were then asked to explain from a structural viewpoint. Other questions, like item C, were used to promote use of the software in an exploratory fashion. Additional questions like items D and E took advantage of the *Select* function to reinforce the meaning and importance of multiple material properties. Beyond the homework assignments, students were also encouraged, but not required, to use CES4 for the project component of the course, if they had elected to do a project.

Student response to the use of CES4 was gathered via an end-of-course questionnaire that addressed many additional components of the course and a variety of student attitudes. Bonus points toward their grade were given as an incentive for completing the questionnaire. The main objective for questions focusing on CES4 was to probe how much they used it and their general attitude about its use. Specifically, students were asked whether they used CES4 only when it was required as part of a homework assignment or whether they also used it on their own initiative. (They were instructed not to consider their project work for this question.) They were also asked to rate the usefulness of a variety of course activities, CES4 among them, in learning the course material. In addition, they were asked to indicate their level of agreement as to whether use of CES4 should be continued, both if it were free and if students were required to pay $20 for it.

As previously explained, the Myers-Briggs Type Indicator (MBTI) was used as a measure of students' learning style. MBTI data were already available for many upperclass students who had completed the Form M questionnaire upon entry to WPI. Anyone whose type was not already in the archive was asked to complete that instrument over the web. Again bonus points were offered as an incentive for completion. (An alternative for bonus points was given to students who had already completed the instrument.) As recommended for MBTI testing, students were encouraged to attend a feedback session to verify and learn about their type, but data were not altered based on the results of feedback sessions. MBTI data were linked to questionnaire data via student ID numbers. Students were assured that ID numbers would never be linked with their names.

Table 3 shows response rate information for the MBTI and course questionnaire. Although the response rates were relatively high, students who did not respond to the end-of-course questionnaire had a significantly lower final average than the respondents. The final letter grade distribution, however, was not significantly different between respondents and non-respondents. Nonetheless, the population of students for which both MBTI and end-of-course questionnaire data are available can be considered only marginally representative of the entire class.

Table 3: Response Rate Information

Student Population	N	Mean final average	*p** (t-test)	*p* (chi-square test on letter grades)**
All	90	78.9		
MBTI respondents	73	79.8	0.19	0.53
MBTI and questionnaire respondents	68	81.1	*0.02*	0.37

*The t-tests compared the mean final averages of respondents vs. non-respondents. The *p* value is the probability that observed differences are due to chance; values less than 0.05 are generally interpreted to indicate statistically significant differences.

**The chi-square test compared the letter grade distribution (A-B-C-No Record) of respondents vs. non-respondents. The *p* values indicate the probability that the difference in letter grades was due to chance.

Beyond the limitation associated with a marginally-representative sample, it is important to acknowledge some additional limitations of this research design, which arise both from the way in which CES4 was used in the context of this particular course, and from the limited information that was gathered from students about its use:

- CES4 was a relatively minor component of the course, so the findings of this study cannot be expected to reflect possible type-dependent responses and student attitudes if the software were used more extensively in upper-level courses.

- We cannot assume that student use of the software outside of the homework assignments is influenced only by learning style. There could be mitigating or spurious factors like other courses they happen to be taking simultaneously (e.g., a mechanical design course).

- Because of the close-ended nature of the survey questions, we do not know the reasons behind students' perception of usefulness of the software, or whether they really became comfortable using it. In addition, there are no performance or learning measures that can be directly associated with CES4. In a future study, it might be beneficial to collect information on student performance on homework questions that utilized CES4.

V. Results and Discussion

Students' assessment of the usefulness of CES4 in learning the course material showed some marginal dependence on MBTI dimensions, providing modest support for some of the hypotheses described in Section III. Students rated usefulness on a scale from 0 (did not use) to 4 (very useful); the results are shown in Table 4. Sensing students, on average, rated CES4 more useful than did Intuitive students, in line with expectations of type theory. Sensors likely appreciated the tangible information on products and applications and the detailed lists of material properties. Note, however, that the S-N difference is not statistically significant. Thinkers, who are likely to appreciate a decision-making tool that is based on objective information, found the software more useful than Feelers, but again the difference is not statistically significant.

Table 4 shows that the difference between Judging and Perceiving students does approach marginal statistical significance, with Judgers rating the software more useful to their learning. Furthermore, when the J-P scores are treated as a continuous quantitative variable, there is a significant correlation between scores on the J-P dimension and ratings of usefulness (Pearson correlation, $\rho = -.320$, $p = .009$). In other words, as the preference toward Perceiving becomes stronger, students' ratings of usefulness of the software decrease. Recall that I had expected that the discovery and impulse opportunities of CES4 might especially appeal to Perceiving students. The findings do not support that hypothesis. It may be that the "decisive" element of CES4 dominated over the exploration opportunities. In hindsight, this finding is not surprising since more homework questions directed students toward making material selection decisions and organizing material property information rather than promoting unstructured exploration.

Table 4: Students' Ratings of Usefulness of CES4* as a Function of MBTI Dimensions				
	N	Mean	Std. Dev.	*p***
OVERALL	68	2.15	.966	
Extrovert (E)	30	2.10	.960	.724
Introvert (I)	38	2.18	.982	
Sensing (S)	40	2.25	.954	.297
Intuitive (N)	28	2.00	.981	
Thinking (T)	42	2.24	.983	.327
Feeling (F)	26	2.00	.938	
Judging (J)	32	2.34	.937	.114
Perceiving (P)	36	1.97	.971	

*Students rated "usefulness in helping learn the course material," on a scale of 0= Did not try; 1= Not useful; 2= Somewhat useful; 3= Useful; 4= Very useful

**Independent samples t-test. *p* indicates the probability that the null hypothesis should be rejected. Values less than .05 are considered to indicate statistically significant differences, while values less than 0.10 suggest marginal significance.

The data were also analyzed to explore whether there are interactions between MBTI dimensions. One such interaction proved to have marginal statistical significance, as shown in Table 5. An analysis of variance showed that while the E-I and S-N dimensions considered separately did not have a significant effect on students' perceptions of usefulness of the software, there was interaction between those two dimensions, at a marginal level of significance (p= .088). Examination of Table 5 shows that students with both Introversion and Intuition (IN) preferences rated the usefulness of the software significantly lower than other types, especially compared to those with both Introversion and Sensing (IS) preferences. This finding is reinforced by the research base on type theory, which has shown that IN types tend to prefer activities like

Table 5: Students' Mean Ratings of Usefulness of CES4 Software* Showing Interaction between E-I and S-N MBTI Dimensions			
	Sensing (S)	Intuitive (N)	Total
Extroversion (E)	2.00 (N=15)	2.20 (N=15)	2.10 (N=30)
Introversion (I)	*2.40*** (N=25)	*1.77*** (N=13)	2.18 (N=38)
Total	2.25 (N=40)	2.00 (N=28)	2.15 (N=68)

*Students rated "usefulness in helping learn the course material," on a scale of 0= Did not try; 1= Not useful; 2= Somewhat useful; 3= Useful; 4= Very useful

**Interaction between E-I and S-N variables is marginally significant (p=.088, ANOVA) serious reading, while IS types value activities like computer-assisted instruction and audiovisual aids.[5] To the extent that IS types may have difficulty learning from traditional textbooks, CES4 would seem to be a useful supplement for these types of learners.

Students were also asked if they used CES4 only when required or whether they also used it on their own initiative. Twenty-one out of 55 respondents (38%) reported using CES4 on their own initiative. Extroverts were more common in this group than introverts: 46% of E respondents reported using CES4 on their own initiative, while only 33 of Is did so. This difference was not statistically significant, however, and there were no other type-dependences in student response. There was also no significant dependence on major or class year.

Table 6 summarizes student support for continued use of the CES4 software. There were no type-dependent differences in students' recommendations. Not surprisingly, students who reported CES4 more useful to their learning tended to recommend its continued use more highly, whether the software would be free (Pearson correlation, $\rho = .491$, p=.000) or if students would need to pay for it (Pearson correlation, ρ =.459, p=.000). Overall, the results in Table 7 suggest that although there is strong support for use of the software if it does not cost the students anything, support dwindles at the prospect of paying $20 for it. It is possible that if the software were used more extensively, if it were used in other courses also, and/or if the textbook used in the course were less expensive, students might consider the cost justified. Each of these alternatives will be explored for the next offering of the course.

Table 6: Student Support for Continued Use of CES4

	Number (Percent) Responding*				
	SD	D	N	A	SA
Would recommend continued use if free	0 (0%)	4 (6%)	5 (7.5%)	28 (41.8%)	30 (44.8%)
Would recommend continued use even if students must pay $20	14 (20.9%)	22 (32.8%)	18 (26.9%)	13 (19.4%)	0 (0%)

*SD= Strongly disagree; D= Disagree; N= Neutral; A= Agree; SA= Strongly agree

VI. Conclusions

The functionality of Cambridge Engineering Selector (CES4) software has been analyzed in the context of psychological type theory to predict its potential as an effective materials science learning tool for students with various learning styles. While only marginally significant, there were several type-dependent differences in students' ratings of the usefulness of the software in helping them learn the course material:

- Judging students, on average, reported it to be more useful than Perceiving students, likely reflecting dominant use of the software as a structured decision-making and analysis tool rather than as a means of unstructured exploration. One of the primary reasons for experimenting with CES4 was the hypothesis that it would appeal to Perceiving students, who tend to struggle in traditional engineering curricula. While that hypothesis was not supported by this research, it is quite possible that by offering more options for unstructured use of the software, that Ps may find it to be more useful.

- The Extroversion-Introversion (E-I) and Sensing-Intuitive (S-N) dimensions interact to influence student response to the software. IS types (Introversion, Sensing) found it to be more useful than did IN types (Introversion, Intuitive), likely reflecting the software's attention to products and applications and the detail about properties that it provides. Since IN students tend to be successful with traditional textbooks and lectures, providing a useful resource to IS types is attractive from a teaching perspective.

About one-third of the respondents, regardless of their learning style, used the software on their own initiative, even when it was not required as part of a homework assignment. Although I have no data for comparison, that figure seems sufficiently high to suggest that the software served as a learning resource for a broad range of students. From a research perspective, this study could be extended and strengthened by addressing some of the limitations associated with the specific and rather limited way in which the software was used in this Introduction to Materials Science course, and by gathering more qualitative information from students about how they used the software as a learning tool, especially when they did so on their own initiative.

Acknowledgements

Matthew Gdula, Christopher Littlefield, Michael Mancuso, and Ryan Rand, guided by Professor John M. Wilkes, coordinated the administration of the MBTI instrument to students in the course and created a database of the results.

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Biographical Information

CHRYS DEMETRY is Associate Professor of Mechanical Engineering in the Materials Science and Engineering Program at Worcester Polytechnic Institute. Her teaching and research interests include use of educational technology, influence of learning styles on teaching and learning, and K-12 engineering outreach. She received the ASM Bradley Stoughton Award for Young Teachers in 2000 and WPI’s Trustees’ Award for Outstanding Teaching in 2002.