Predicting Entrepreneurial Intent among Entry-Level Engineering Students

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Abstract

This is a continuing study of an instructional technique that teaches important solid mechanics concepts within the context of an entrepreneurship case study and lab that we call Scenario-Based Learning (eSBL). Students in an introductory solid mechanics course completed this class work and then shared their attitudes on the curriculum. Results show that among engineering students, entrepreneurial career intent is closely related to business skill self-efficacy, having a "divergent" learning style, and a "systemizing" approach to problem solving. This suggests that eSBL curriculum could be an important tool in preparing engineering students for a career in entrepreneurship or other business-related activity within core engineering course content. In addition, faculty impressions on instruction using this curricular tool are shared.

1. Introduction: Engineering + X

The career pathway for engineering students overwhelmingly leads to industry. A recent study by the National Science Foundation of newly graduated engineering bachelor and master's degree recipients shows that 75 percent of graduates are employed by "private industry or business."[1] It is apparent from reports like *The Engineer of 2020* that the successful practice of engineering in today's workplace requires the integration of a broad range of skills and abilities that often go well beyond standard engineering curricula.[2] This can include interpersonal skills such as teamwork, communication and persuasion, and business skills such as entrepreneurship, budget management, customer knowledge and marketing.

The key question this pilot research hopes to answer is … *how can engineering educators meet the dual challenge of preparing students for the rigor of an engineering career while simultaneously providing relevant perspectives that prepare engineering graduates for success in the workplace?* In this paper we refer to the teaching of core engineering skills as "engineering" and the relevant skills beyond engineering as "+ X," hence the designation "Engineering + X."

To meet this challenge, the engineering educator faces two fundamental difficulties. First, engineering is typically taught as a series of discrete competencies that may or may not purposely integrate – think of these competencies as "trees." Second, there is little room in any engineering curricula to accommodate extra, non-engineering course work[3] - the larger "forest," in this context. As a result, the traditional approach to engineering education often requires the individual student to integrate his or her own engineering learning into a larger context. Is there a way to help students "find the forest" among the "trees" of engineering education?

We propose a new approach to teaching college-level engineering that contextually frames core engineering concepts with perspective from another knowledge domain in a way that encourages integrative thinking – the scenario-based learning approach (Figure 1). This begins with identifying the interrelated core engineering concepts to be taught, identifying a complimentary

set of related "+ X" concepts and framing them in a scenario or story that encourages abstract-concrete integration that requires the student to make a choice on how to move forward.
For this test effort, we propose a very specific starting point: the entry-level mechanical engineering curriculum (statics) and a "+ X" of entrepreneurship delivered in the context of business school-style scenarios and engineering type hands-on lab experiences.

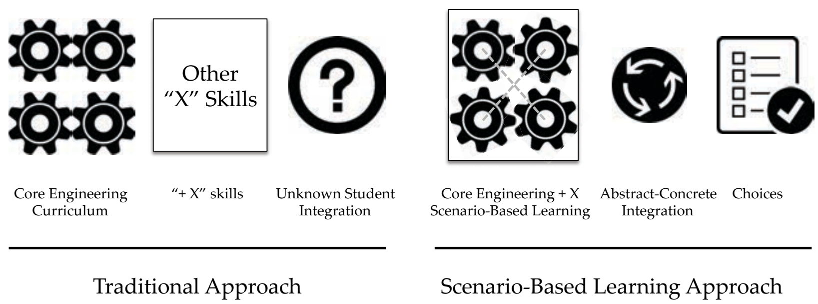


Figure 1 - The traditional approach to engineering education compared to the proposed scenario-based learning approach that stimulates integrative thinking

A metaphor for this curriculum approach is calcium–fortified orange juice. Most everyone knows the value of vitamin C in orange juice and the pleasing unique taste makes orange juice a favorite on the breakfast table. Milk brings important calcium fortification and is an important element of a "good breakfast." Despite these benefits, consumers are reluctant to drink both a glass of orange juice and a glass of milk in one sitting. One answer answer is calcium-fortified orange juice – all the goodness of orange juice and the imbedded calcium fortification of milk in one glass. In this context, the engineering content is the "orange juice," while entrepreneurship (the "+ X") is the "calcium-fortified," combined in a single educational experience.

2. Entrepreneurial Scenario Based Learning Foundations

The overarching pedagogical concept that shapes entrepreneurial scenario-based learning (eSBL) is integrative thinking. Integrative thinking is the ability to "constructively face the tensions of opposing choices, and instead of choosing one at the expense of the other, to generate a creative solution that contains elements of the individual choices and is superiors to each."[4] The eSBL approach challenges the student to process via integrative thinking by moving the problem space from the classroom and placing the student within the "social world." The engineering content and other domain content, with the support of the instructor, help the student arrive at new models for understanding and ultimately solving problems. Finally, the resolution of the scenario informs future course decision-making.

In the construction of eSBL curriculum, we are guided by two learning models: 1) the Kolb experiential learning model (the interaction between abstract conceptualization and concrete experience) as framework for developing the scenarios and evaluating student interaction, and 2) the Baron-Cohen synthesizing-empathizing model (SQ/EQ) that describes the tension between understanding the rules underlying a system (SQ) and understanding social influences (EQ). The ratio of SQ to EQ has been shown to be an important predictor of gender-based participation in the physical sciences.[5]

Based on Learning Styles: In this study, we postulate that scenario-based learning generally aligns with Kolb's learning model through his four primary learning styles[6] of Diverging, Assimilating, Converging and Accommodating, as described in Table 1. The scenario story is a converging experience where the student acquires facts about the situation and anticipates experimentation. The hands-on lab is an assimilating process, linking learning by doing with the experience of working with a team. The lab discussion is a diverging experience with students sharing perspectives and different models of interpretation. Finally, homework is an assimilative experience where the student reflects on learning and practices integrative thinking.

Table 1 - Kolb Learning Styles

Converging (AC+AE)/2	The dominant learning abilities are Abstract Conceptualization (AC) and Active Experimentation (AE). People with this learning style are best at finding practical uses for ideas and theories. They have the ability to solve problems and make decisions based on finding solutions to questions or problems. In formal learning situations, people with this style prefer to experiment with new ideas, simulations, laboratory assignments, and practical applications.
Assimilating (AC+RO)/2	The dominant learning abilities are Abstract Conceptualization (AC) and Reflective Observation (RO). People with this learning style are best at understanding a wide range of information and putting into concise, logical form. In formal learning situations, people with this style prefer readings, lectures, exploring analytical models, and having time to think things through.
Diverging (CE+RO)/2	The dominant learning abilities are Concrete Experience (CE) and Reflective Observation (RO). People with this learning style are best at viewing concrete situations from many different points of view. In formal learning situations, people with the Diverging style prefer to work in groups, listening with an open mind and receiving personalized feedback.
Accommodating (AE+CE)/2	The dominant learning abilities are Concrete Experience (CE) and Active Experimentation (AE). People with this learning style have the ability to learn from primarily "hands-on" experience. In formal learning situations, people with this style prefer to work with others to get assignments done, to set goals, to do field work, and to test out different approaches to completing a project.

Taking an Empathetic Approach: We designed eSBL curricula to be empathic. Empathy is of central interest to our work because empathy has been found to predict entry into the physical sciences and humanities and college-level major[7] and empathetic curricula may be a way to attract more women to careers in engineering.

Empathy covers a range of cognitive behaviors from caring for other people and having a desire to help them, to experiencing emotions that match another person's emotions, to knowing what the other person is thinking or feeling, to blurring the line between self and other.[8] Women tend to exhibit a preference for empathetic situations at a higher level than do men.[9]

In the eSBL curriculum, each scenario story is person-centered, meaning that it features a human protagonist working through engineering and entrepreneurial problems. It was our goal to be engaging to both female and male students. We would also expect the eSBL curricular approach to be more appealing

For the purpose of this study, we uniquely refer to this as "Engineering Empathy" and define it as *"the* skill *and skill of engineering practiced through interaction with the social world; where human wants, needs and desires form the source of engineering inspiration and execution.* "To the extent that eSBL curricula may engender engineering empathy, it would increase engagement and satisfaction with the learning process, which is considered a precursor to persistence in an engineering major.

We used Baron-Cohen's synthesizing-empathizing (SQ-EQ) instrument to understand the tension between understanding social influences (EQ) and understanding the rules underlying a system (SQ), as it relates to this curriculum experience. Systemizing is defined as the drive and ability to analyze the rules underlying a system, in order to predict its behavior and appears to be central to the understanding of engineering. Empathizing is defined as both the interest and ability to identify another's mental states and to respond to these with one of a range of appropriate emotions.[10]

The SQ-EQ model places these cognitive styles in tension and compares the relative strength of these styles within individuals as a predictor of their cognitive behavior. For example, S>E is an individual that favors systemizing thinking over empathizing thinking, while E>S is an individual that favors empathizing over systemizing. Studies show a consistent pattern with the "S>E profile for physical science students as a group, and a E>S profile for humanities students as a group, regardless of sex."[11]

3. Scenario-Based Curriculum for Solid Mechanics

The scenario-based learning has long been used as a pedagogical technique in a variety of learning domains, primarily in business education where it is viewed as a technique to teach complex decision-making skills.[12] In engineering education, the scenario approach is most often used in the teaching of engineering ethics that focus on the ethical challenges of professional engineers and use "social world" stories like the Challenger disaster or Hurricane Katrina.[13] The NSF has funded previous efforts in engineering ethics scenarios including the development of thirty-three engineering ethics scenarios (DIR-8820837, 1992) and a deployment workshop (1995). These are archived in the Zachry Department of Civil Engineering at Texas A&M.[14]

In this research, the scenario-based learning approach moves beyond previous case method curricula by incorporating a four-module pedagogical process, as shown in Figure 2. The process begins with the scenario or story, a four to six page description of the situation. The scenario features protagonists (both male and female) who are recent engineering graduates struggling with a "social world" problem and contains relevant information required to solve the challenge. The scenario does not include core engineering content, as this is covered in regular class sessions, but it does include instruction in "+ X" content (in this project, entrepreneurship) which would not be covered in class sessions.

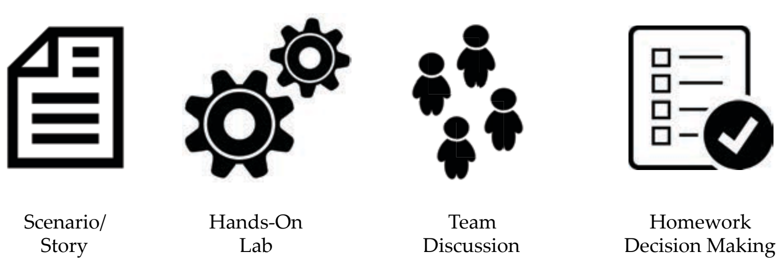


Figure 2 - Scenario-Based Learning pedagogical elements

The second and third steps of this process are what distinguish this curriculum from previous case study curricula because it involves a “social world” hands-on experiences (in the form of a lab) that lead to a group discussion of the data and possible decision options. The hands-on lab takes about 50-60 minutes of class time and involves four students working as a team. The third step is a structured team discussion, reviewing the data collected and talking about different models of interpretation (see Figure 3). The final step in the process is a homework assignment that requires students to synthesize their learning and make a choice for how they would proceed as a character in the story.

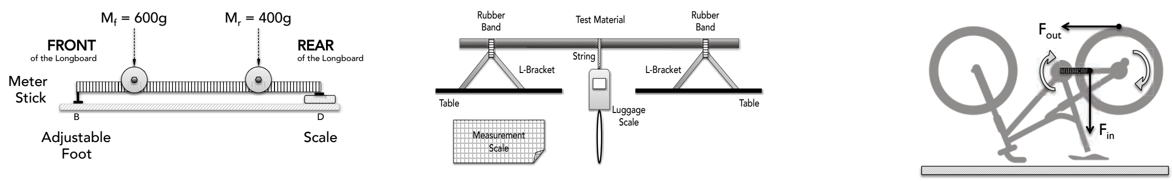
Figure 3 - Integrative Learning in-action (starting upper left): Trek B-cycle lab, Madison Longboard Deck lab, full class (94 students) participating in a lab experience and discussion

The scenarios incorporate engineering concepts drawn from a popular undergraduate engineering textbook.[15] The entrepreneurial concepts are drawn from a popular textbook[16] on entrepreneurship. The three eSBL cases developed to date are summarized in Table 2. As an example, the Trek B-cycle scenario materials are attached as Supplemental Documentation.

Table 2 - eSBL Engineering and Entrepreneurial Content

	Madison Longboard 1: Choosing a Truck	**Madison Longboard 2:** Designing a Deck	**Trek Bicycle Corporation:** B-cycle Drive Train
Engineering Content	Free-body diagrams Normal Force Equilibrium Analysis Moments Moment Center Planar Systems	Modulus of elasticity Deflection Neutral Axis Cantilever beam Bending stress Design for deflection	Mechanical Advantage Output Load/Input Load Gears Speed Ratio Multiple FBD’s
Entrepreneurial Content	Business model Value proposition Revenue model Cost model Profit model	Vision statement Mission statement SWOT analysis Business risk Business uncertainty	Personas Empathy map Product planning Interpersonal relationships Vendor relations
Lab	Moveable weights, meter sticks, jeweler’s scale	Material samples, angle brackets, tube scale	Bicycle, blue tape, paint stir stick, tube scales

As used in the pilot deployment, each case study was accompanied by a three-page worksheet that was completed as part of the lab experience and a one page homework assignment that covered the entrepreneurial concepts. The lab experiences were designed to use practical and inexpensive materials an entrepreneurial engineer might use to help make decisions. The set-up for the labs is shown in Figure 4**.**



Longboard: Trucks Beam Analysis | **Longboard: Deck Deflection** | **Bicycle Mechanical Advantage**

Figure 4 - Scenario-Based Learning lab materials and lab set-up

This scenario-based curriculum is the second-generation version of curriculum. Results from this previous research with the earlier version show that students can increase their knowledge of targeted entrepreneurship concepts without diminishment of learning core engineering concepts.[17] While the case study experience did not significantly change entrepreneurial career intentions it did grow students' perceived entrepreneurial self-efficacy (as measured by confidence in business skills), which can be a precursor to changing career intent.

4. Research Hypotheses

The intent of this curriculum is to introduce entrepreneurial concepts in the context of entry-level engineering curriculum in the hope that it would have a positive impact on the students' entrepreneurial career intent. Therefore, our research hypothesis is:

> *The incorporation of entrepreneurial content into core engineering curriculum will have a positive impact on engineer students' entrepreneurial career intent.*

We also intend to look at other factors beyond entrepreneurial content that may contribute to changes in entrepreneurial career intent; to move toward an integrated model of what it takes to drive interest in entrepreneurship among engineering students.

5. Methodology

This pilot research was conducted to determine how scenario-based learning curriculum appealed to different kinds of students and only to a lesser extent, measure the efficacy of the pedagogy. As a result, this research contains no randomized controls and therefore lacks the ability to make causal inferences about the effect or impact of educational experiences. The case study and labs were integrated into a 10-week, 20-session introductory engineering solid mechanics course at a western private university in the fall 2013 and winter 2014 quarters. A week-by-week overview of the class is shown in **Table 3**.

Table 3 - Solid Mechanics course overview by-week showing learning topics and placement of the three (**bold**) entrepreneurial case study/labs

Week	Topics	Lab	Homework
1	Forces: Vocabulary, Representations and Manipulation - Math Basics		Forces
2	Moments: Representation and Equivalent Load	Tower Design	Moments
3	Equilibrium: Summing Forces and Moments **Entrepreneurship Case Study**	**Longboard -Trucks**	Equilibrium Entrepreneurship
4	Free Body Diagrams: The Key Image	Device Operation	Free Body Diagrams
5	Equilibrium: Analysis and Trusses Safety Factors - Ethics	Hyatt Ethics Case	Trusses
6	Bridges: Design and Construction	Design Exercise	Bridge Report
7	Analysis of Machines **Entrepreneurship Case Study**	**Bicycle Analysis**	
8	Analysis of Beams: Loads and Stresses **Entrepreneurship Case Study**	**Longboard - Deck**	Frames, Machines, Beams Entrepreneurship
9	Statically Indeterminate Problems Role of Friction in Equilibrium		Friction and Statically Indeterminate
10	Analysis of Distributed Loads		Final Project Poster Session

The class includes seven in-class labs, as well as a final, student directed project. Each class session lasted about two-hours. Generally, the first weekly class session was dedicated to a lecture on the relevant solid mechanics topics, while the second weekly class included a lab experience.

Participant Demographics: The participant base included students enrolled in an entry-level solid mechanics course during fall quarter 2013 and winter quarter 2014. Most of the respondents were planning to declare a mechanical engineering major (but at this stage of their education many have not officially declared a major) and other students expressed interest in computer science, civil engineering, physics and mathematics.

Participation in the pre-survey (n = 182) was required as part of enrollment in the course and participation in the post survey (n = 100) following the conclusion of the course was voluntary and included a small monetary reward ($10 gift certificate). The career intent was measured pre-post to access any change, while lab satisfaction was measured in the post survey.

Most of the following analysis was completed among the 100 students who completed valid pre and post surveys: 47 female (47%) and 53 male (53%). Final course scores among students who completed both the pre-and post surveys showed no statistical difference between gender groups (88.8% f, 90.1% m, 89.5% total). However, there is a statistical difference in final course scores between students who completed only the pre survey (85.8%) and both surveys, (t (113) = 2.71, p = .01, d = .43).

Measure of Career Intent: Student respondents were asked during pre-enrollment and a second time after the course final had been completed about their career intention using the question, *"Looking into your future, over the 5 years from your graduation how likely are you to do any of the following?"* The choices included founding a company, working for a small business/start-up, medium or large size US-based business, multi-national global business, government and non-profit. Responses were collected using a 5-point Likert scale of likelihood ranging from Very Unlikely (1) to Very Likely (5) with (3) as neutral. This question was adapted from a longstanding alumni survey instrument.[18]

In some cases, we will refer "pre-post career intent," which is a measure of change in a student's career intent for career choices post the eSBL curriculum experience minus the career intent of that same student before (pre) the eSBL curriculum. A positive "pre-post career intent" score indicates an increase in preference for a particular career option.

Measure of Business Self-Efficacy: Student respondents were asked pre-and-post the lab experiences about their confidence to perform in a series of business-related skills. This item was drawn from previous studies on engineering persistence[19,20]. The question was *"How confident are you in your ability to do each of the following at this time?"* The eight choices included recognizing a good idea, financing a new business, selecting a marketing approach, negotiating prices with a supplier, leading a team of people, and promoting accomplishments. Responses were collected using a 5-point Likert scale of confidence ranging from Not Confident (1) to Extremely Confident (5) with (3) as neutral. The self-efficacy ratings of business-related skills showed high reliability ($\alpha = 0.88$ pre, .91 post), so the items were averaged to give an overall pre-and-post business skill self-efficacy score.

Measures of eSBL curriculum satisfaction, lab element satisfaction, Kolb Learning Style Indicator and Baron-Cohen SQ/EQ Instrument were administered the final week of class, two weeks after the final eSBL experience.

Measures of Scenario-Based Learning Satisfaction and Integrative Thinking: eSBL satisfaction was measured with a question drawn from Garcia et al.[21] This question asked about satisfaction with the overall eSBL experience and included 8 items, shown in Table 4. Responses were collected using a 5-point Likert scale of agreement ranging from Strongly Disagree (1) to Strongly Agree (5) with (3) as neutral. The items had high reliability ($\alpha = .82$), so they were averaged to form a single eSBL satisfaction score.

Table 4 - Scenario-Based Learning satisfaction measure, with reverse scored items (r) and integrative thinking measures (*italic*)

Item	Scenario-Based Learning Satisfaction Questions
1	I felt that the use of case study was relevant in learning about the course concepts
2r	I was frustrated by the ambiguity that followed when using the case study
3	*The case study helped me synthesize ideas and information presented in the course*
4	I was more engaged in class when using the case study
5	*The case study allowed me to view an issue from multiple perspectives*
6r	I found it hard to relate to one or both of the characters in the case study
7	*I'm now confident that I can do both the engineering work and make the business decisions in the case study*
8	I felt that what we learned in the case study was applicable to my future career

Integrative Thinking was measured using a 3-item subset of the eSBL satisfaction instrument. These items were selected because they best described Martin's characteristics of integrative thinking. The items included (3)*"the case study helped me synthesize ideas and information from the course,"* (5)*"the case study allowed me to view an issue from multiple perspectives,"* and (7) *"I'm now confident that I can do both the engineering work and make the business decisions in the case study."* The items had an acceptable reliability ($\alpha = .66$), so the items were averaged to form a single Integrative Thinking measure.

Lab Element Satisfaction: Students rated each element of the eSBL experience: case study story, hands-on lab exercise, in-class work sheet, group discussion and homework – for each of the three lab experiences. Responses were collected using a 5-point Likert scale of liking ranging from Dislike Extremely (1) to Like Extremely (5) with (3) as neutral. For each lab, the element ratings items had acceptable reliability ($\alpha = .65$ to $.72$), so they were averaged to a single satisfaction score for each lab. Similarly, for each element, the lab ratings had acceptable reliability ($\alpha = .65$ to $.90$), and were averaged to a single satisfaction score for each lab element.

Kolb Learning Style Indicator (LSI): The Kolb LSI is a 48 items instrument[22] that results in four trait-level learning style preference indicators - concrete experience (CE), reflective observation (RO), abstract conceptualization (AC) and active experimentation (AE). Kolb states that four learning styles form at the intersection of these traits – "diverging" (μ:CE+RO), "assimilating" (μ:RO+AC), "converging" (μ:AC+AE), and "accommodating" (μ:AE+CE). Participant's scores for each learning style were converted to a T-score ($\mu = 50$, +/- 10 = 1 SD). Participants were "typed" by their primary learning style, which is the highest T-scored learning style for each participant. The number of participants by Kolb Learning Style type is shown in Table 5.

Table 5 - Kolb Learning Style Score by Primary "Type"

Kolb Learning Style	**Diverging**	**Assimilating**	**Converging**	**Accommodating**
T-score μ	55.7	56.8	56.3	57.8
# Participants	13	26	34	27
% Total	13%	26%	34%	27%

Baron-Cohen SQ/EQ Instrument: To measure SQ (systemizing quotient) and EQ (empathizing quotient), we used the Wakabayashi's SQ-Short and EQ-Short instruments.23 SQ-Short (25-items) and EQ-Short (22-items) instruments ask agreement/disagreement with statements of personal description. Both the SQ and EQ instruments use a forced choice format, which ranges from Strongly Agree to Strongly Disagree with no neutral choice. Participants' scores for SQ and EQ were normalized using the instrument population norms by gender and converted to a T-score ($\mu = 50$, +/- 10 = 1 σ). Participants were "typed" based on the difference between SQ and EQ (SQ T-score – EQ T-score) scores with increments of 10-point difference (1 σ) defining categories, as shown in Table 6.

A score falling between ±10 points is termed "Balanced," between +10 to +20 a "Type S," and +20 "Extreme Type S." A score falling between - 10 to -20 is termed a "Type E," and -20 and below is an "Extreme Type E."

Table 6 - SQ/EQ Type by study participants

SQ/EQ Type	Extreme S	Type S	Balanced	Type E	Extreme E
Type Range	D ≧ 20	20 > D ≧10	10 > D > -10	-10 ≧ D > -20	-20 ≧ D
SQ-EQ (D) μ	23.5	14.7	2.6	-14.1	NA
# Participants	4	30	65	1	0
% Total	4%	30%	65%	1%	0%

Statistical Analyses: The primary data set for these analysis are the participants who answered both the pre-and-post surveys (n = 100) that allows single sample, paired comparison. Sample normality for all continuous variables was assessed through kurtosis and skewness (range of ± 1.5), and the data were normally distributed. Survey item consistency was measured using Cronbach's Alpha (α) +.60 considered reliable. Correlations were done as Pearson Product Moment Correlations (*r*) with two-tailed significance. The level of statistical significance (*t* and *F* statistics) for all analysis is *p*-value < 0.05 and effect size (Cohen's *d*) is reported using conventional norms for range (.10 < *small* > .30 < *medium* > .50 > *large*). All analyses were done with R[24] and add-on packages.[25,26]

6. Pilot Research Results – Descriptive Statistics

Lab and eSBL Satisfaction – Overall, students had a positive reaction to the labs and the scenario-base learning approach, as shown in Figure 5. The three labs were rated between 3.38 and 3.63 (on a 5 point scale), which are statistically greater than a 3.0 neutral rating. Not surprisingly, students rated the hands-on, in-class lab experience (3.87) significantly higher than the case story (3.38), ($t\,(99) = 7.03$, $p = .00$, $d = .71$). Finally, the eSBL curriculum received a mean satisfaction rating of 3.46, again statistically higher than a 3.0 neutral rating.

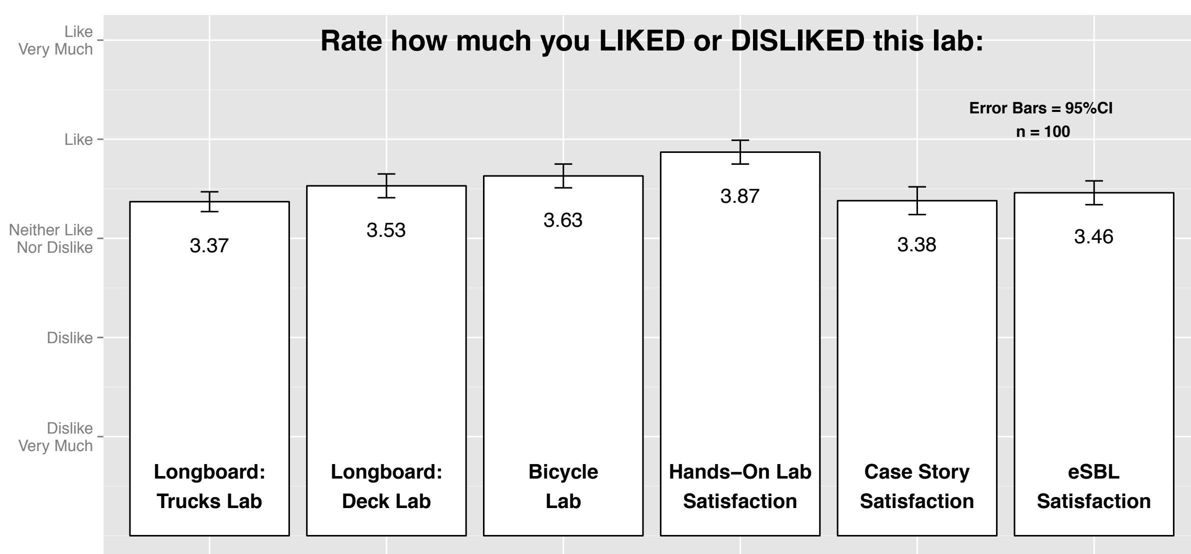


Figure 5 - Lab and eSBL satisfaction ratings

As stated earlier, we had guessed that the eSBL curriculum might appeal to female students more than to male students. The data show this is not the case as female student satisfaction with the eSBL curriculum (3.37) is not statistically different that male student satisfaction (3.53), (t (95) = 1.36, p = .18, d = .27). Female student satisfaction with the case stories (3.26) was lower but not significantly lower than male satisfaction with the case stories (3.49), (t (98) = 1.76, p = .08, d = .35), nonetheless indicating we can make the case stories more appealing to female students.

Overall, final course score seemed to have little relationship with eSBL satisfaction. The course score correlation coefficient with eSBL satisfaction (r = .06, p = .49) indicates that satisfaction with the eSBL curricula had little relationship with how well the student performed in the class. Of interest, there was no correlation between course score and career interest in founding a company (r = -.15, p = .13) or any other career option surveyed.

Career Intent – Overall, there were no significant changes in career intent pre-and-post exposure to this curriculum, as shown in Figure 6. The career intent rating for "launch a start-up" was the same 3.01(out of 5.00) pre and post and there were no significant changes in pre and post career intent for any other career option. This would indicate that the eSBL curriculum was not sufficient to change career intentions, which is not surprising given its limited role in the overall curricula for the course.

Of additional interest are the ratings of other career paths, most notably working for a small business or working for a medium/large U.S. company or a global company, which were all statistically greater than ratings for founding a company. In particular, the career path of "work in a small business" (3.62 post) was rated significantly higher than "launch a start-up" (3.01 post), (t (99) = 5.74, p = .00, d = .57), which suggests that students may be more receptive to working as an employee in a start-up environment rather than taking the step of founding a company on their own, often referred to as the difference between a "joiner" and a "starter."

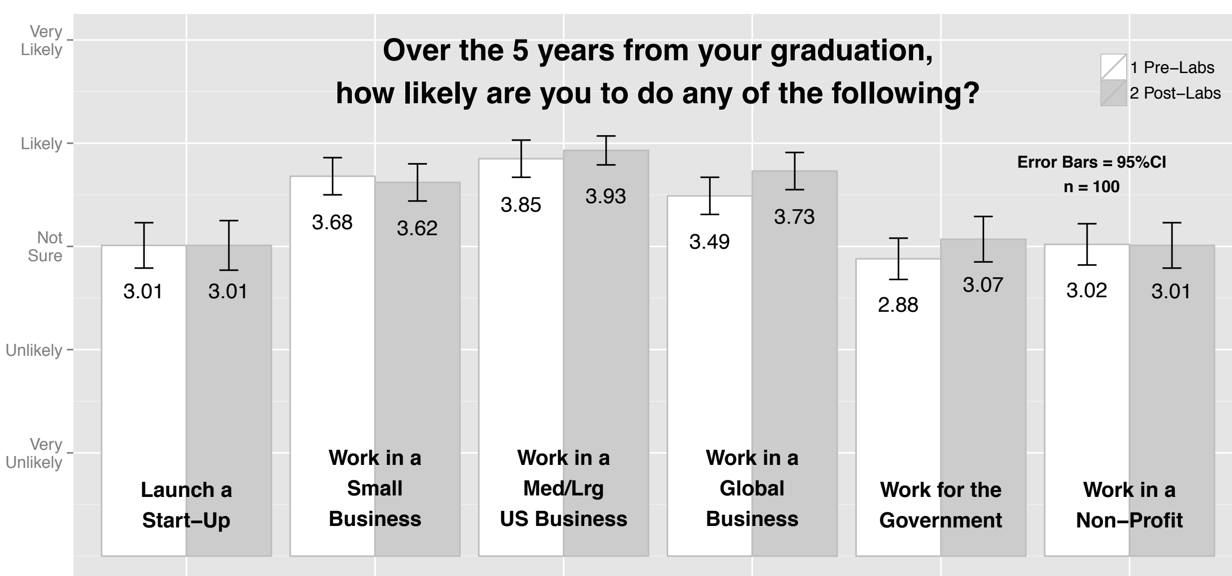


Figure 6 - Pre-Post Career Intent

Business Self-Efficacy - As part of measuring career intent, we also asked students to rate their "confidence in your ability to do" a variety of business skills pre-and-post exposure to the eSBL content. Similar to career intent, there was no overall gain in business skill self- efficacy, as shown in Figure 7. The one exception was "steps to finance a business venture," which showed a statistically significant gain from a mean rating pre (2.03 out of 5.00) to post (2.31), (t (99) = 2.61, p = .01, d = .26). This is unexpected, as none of the eSBL material deal with financing a venture, and it is possible the students are obtaining this information in other courses.

It is interesting to note that students rate their confidence in accomplishing classic business skills much lower than interpersonal skills, both pre and post. On average, classic Business Skills such as "recognizing a good idea," or estimating "the cost of a project" had an overall mean rating of 2.77 (out of 5.00) post the eSBL experience, versus Interpersonal Skills, such as leading "a team of people," or communicating "ideas to others" that had a significantly higher overall mean rating of 3.57 post exposure to the eSBL content. This difference is significant (t (99) = 12.00, p = .00, d = 1.20) and indicates that students had much more confidence in their communication skills over their business skills - an opportunity for future curricula interventions.

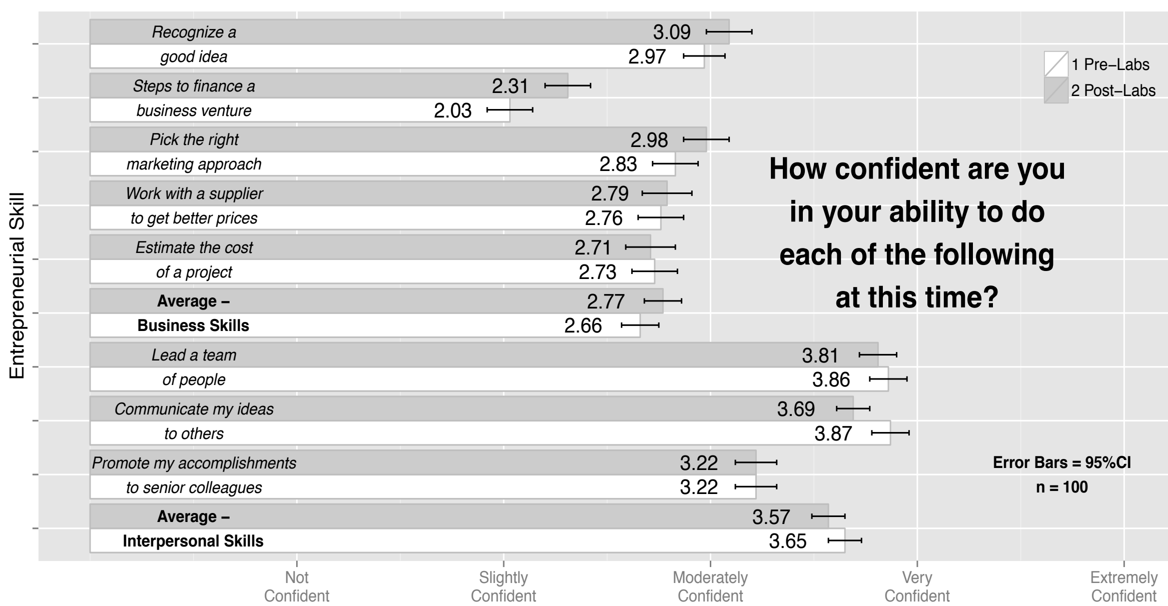


Figure 7 - Self-Efficacy ratings on a range of common business skills

eSBL Curriculum Impact on Career Intent – The key question underlying this research is whether exposure to entrepreneurial content embedded with core engineering concepts leads to a change in career intent. This was expressed as our research hypothesis:

> *The incorporation of entrepreneurial content into core engineering curriculum will have a positive impact on engineer students' entrepreneurial career intent.*

We know that overall, there was not a change in entrepreneurial intent pre-post exposure to eSBL curriculum. However, this could be a balance of students who, once exposed to curriculum, decided that entrepreneurship was not as attractive a career choice, offset by students who knew little about entrepreneurship and became interested once exposed to the curriculum.

Correlation analysis between satisfaction with the eSBL curriculum and career intent suggests that the eSBL curriculum may have had a positive impact on entrepreneurial career intent, as shown in Table 7. A significant positive correlation exists between student satisfaction with the eSBL curriculum and pre-post change in career intent for "founding a start-up" ($r = .20$, $p = .04$) and pre-post change in career intent for "working for a small business" ($r = .31$, $p = .00$). For perspective, no significant correlations were found between eSBL satisfaction and pre-post career intent changes for working for a "medium or large US business," "global business," "government," or "non-profit."

Table 7 – Pearson Correlation Coefficients for eSBL Curriculum Satisfaction and Pre-Post Changes in Career Intent

	Variable	**1**	**2**	**3**
1	Satisfaction with the eSBL Curriculum: Overall	--		
2	Satisfaction with the eSBL Curriculum: Integrative Thinking Items	**.86**	--	
3	Pre-Post Change in Career Intent – *Founding a Start-Up*	**.20**	**.27**	--
4	Pre-Post Change in Career Intent – *Working for a Small Business*	**.31**	**.33**	**.29**

bold p <.05

We suspected that the most difficult aspects of the eSBL curriculum for engineering students might be aspects of integrative thinking - *synthesizing ideas*, using *multiple perspectives to solve problems* and confidence in the ability to *accomplish both engineering and business tasks*. These elements ask the student to look beyond the problem at hand (the "trees" in our metaphor) and see their accomplishments in a broader context (the "forest").

We found that the mean eSBL satisfaction rating for the three integrative thinking items (3.67 out of 5.00) was significantly higher that the mean total (8-item) eSBL score (3.47), (t (99) = 6.63, p = .00, d = .66), including a strong positive correlation ($r = .86$, $p = .00$) between the variables. Similar to overall eSBL satisfaction, satisfaction with the integrative thinking aspects of the curriculum showed a positive correlation with pre-post change in entrepreneurial career intent ($r = .27$, $p = .01$). This suggests that the integrative thinking aspects of the eSBL curriculum are exactly what the students enjoyed the most and may be what facilitates a shift in thinking about a career in entrepreneurship.

We are mindful that correlation does not imply causation, and of course, this study lacks a relevant no intervention control. However, given the consistency of these findings over the career intent for entrepreneurship and small business, we find limited but encouraging support for our research hypothesis that the incorporation of entrepreneurial content within core engineering concepts can lead to greater student interest in pursuing an entrepreneurial career.

Learning Style – We are interested to see how the Kolb learning style represented itself in the classroom and if learning style had any impact on eSBL curriculum satisfaction. It was surprising to see how evenly dispersed the learning styles where throughout the class. The "converging" learning style was the largest grouping with 21 students while the "diverging" learning style had just 13 of the 100 students in the post survey data set. However, these differences did not rise to the level of significance ($x^2 = 2.71$, p = .44) indicating a representative dispersion of styles.

We suspected that students with a self-reported Kolb Learning Style of "accommodating" (favors concrete experience and active experimentation) will show a greater level of satisfaction with scenario-based learning than students who have average or lower than average preference for an Accommodating learning style. Students with an Accommodating learning style had an eSBL curriculum satisfaction mean score of 3.63, compared to a range of 3.34 to 3.42 for the other learning styles, as shown in Figure 8. However, this difference is not statistically significant.

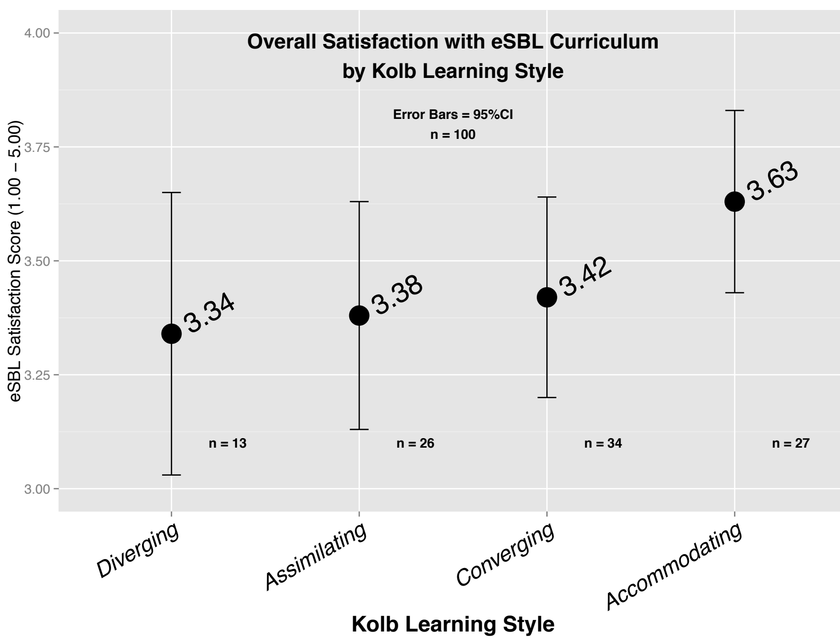


Figure 8 - Mean eSBL curriculum satisfaction scores by Kolb Learning Style

However, we may have learned something about Kolb learning style and career intent, as shown in Table 8. Focusing on students' career intent following exposure to the eSBL curriculum, we find a positive significant correlation between students who favor "founding a company" and the Kolb Diverging style ($r = +.22$, $p = .02$) and Kolb Accommodating style ($r = +.22$, $p = .03$), which both have Concrete Experience as a common factor. Concrete Experience is the ability to internalize the outside world and value the experience, which seems consistent with the behavior stimulated by the eSBL curriculum.

We also learned that students with certain learning styles might be more receptive to entrepreneurial careers. Students with a Kolb Diverging learning style showed a positive correlation with pre-post change in entrepreneurial career intent ($r = +.32$, $p = .00$), while students with a Kolb Converging Style showed a negative correlation ($r = -.31$, $p = .00$), as shown in Table 8.

Table 8 - Pearson Correlation Coefficients relating Kolb Learning Style with Entrepreneurial Career Intent

		Post-eSBL Career Intent: *Founding a Company*		Pre-Post Change Career Intent: *Founding a Company*	
Kolb Learning Style	**Factor**	***r***	***p***	***r***	***p***
Converging	Abstract Conceptualization + Active Experimentation	**-.19**	**.05**	**-.31**	**.00**
Assimilating	Reflective Observation + Abstract Conceptualization	**-.21**	**.03**	-.04	.69
Diverging	Concrete Experience + Reflective Observation	**+.22**	**.02**	**+.32**	**.00**
Accommodating	Active Experimentation + Concrete Experience	**+.22**	**.03**	-.05	.65

We also found that in our sample of engineering students the Diverging style was least prevalent (13% sample) while the Converging style was most prevalent (34% sample). This all may be an indication that eSBL curriculum and a career in entrepreneurship appeal to a specific segment of the engineering student population, perhaps those students who favor a Diverging learning style.

Systemizing Quotient – Empathizing Quotient – As discussed earlier, measured levels of empathy, particularly in combination with measured levels of systemizing have been associated with students' interests in the physical sciences. It is possible that the eSBL curriculum, with its emphasis on person-centered stories might be a way to attract higher-empathy level students, such as women, into the discipline of engineering.

Recall, we measured both systemizing (SQ) and empathy (EQ), then subtracted the EQ score from the SQ score to arrive at a net difference (D), as a general measure of dominance of one style over another. A positive D score is an indication of systemizing thinking over empathizing thinking, while a negative D score is an indication of empathizing thinking over systemizing thinking. Scores between -10 and 10 (a $\pm 1\sigma$ range) represent "balanced" thinking.

In total, fully 99 percent of students fell into "balanced" or "systemizing" categories, as shown in Figure 9. Only one student fell into the "empathizing" category. Thirty four percent of students were classified as "systemizing" or "extreme systemizing," which is less than what is expected from an engineering content course based on data from other research with this instrument. [11,23]

These data also show that female students have a lower SQ-EQ score than male students, indicating more empathy within the female sample, consistent with previous research in this area. The female student D score (SQ-EQ) was +4.3 versus +9.3 for male students, which is a significant difference of +5.0, ($t(99) = 3.39$, $p = .00$, $d = .67$). Previous research among a general population sample shows that over 40 percent female participants have empathizing "brain types" ("Extreme Empathizing" or "Empathizing") versus less that 10 percent for male participants.[23]

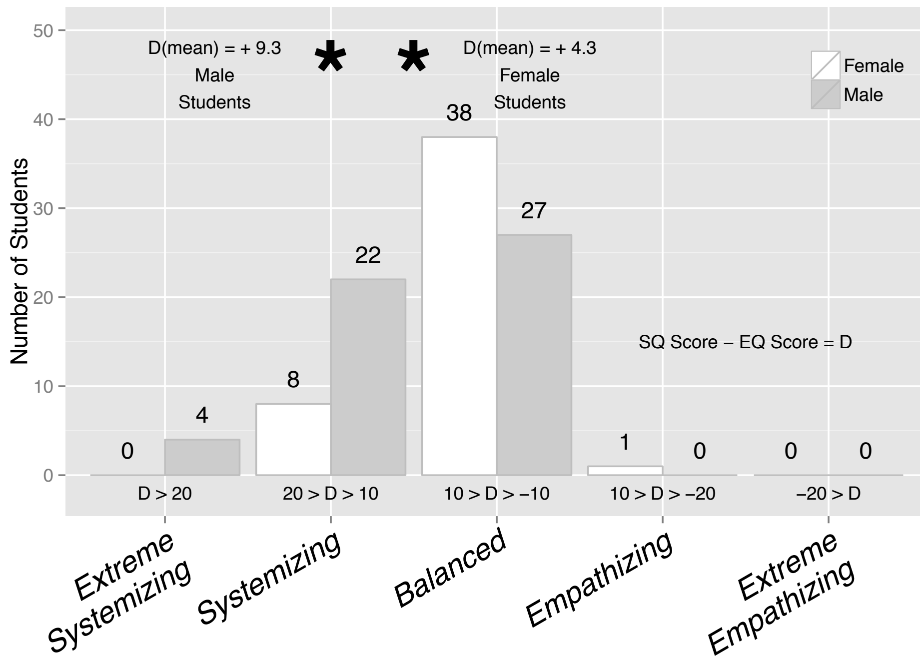


Figure 9 – SQ-EQ scores by student gender

We also see that the eSBL sample in this research is different than similar college-level samples of "science majors" and "humanity majors," with the eSBL sample being more "balanced" than comparison groups, as shown in Table 9. Wakabayashi et al. (2006) measured 1,761 students from Cambridge University who identified themselves as either humanities majors or science majors. The science majors included engineering majors as well as mathematics, physics, astronomy, and physical natural science majors. This comparison group shows that the eSBL sample has the same level of "synthesizing" students (34.0% eSBL vs. 39.6% Cambridge), less "empathizing" students (1.0% eSBL vs. 17.3% Cambridge) and more "balanced" students (65.0% eSBL vs. 43.1% Cambridge).

Table 9 – Percent of Sample by "Brain Type"

		SQ-EQ By "Brain Type"				
	n	**Extreme Synthesizing**	**Synthesizing**	**Balanced**	**Empathizing**	**Extreme Empathizing**
eSBL Sample	100	4.0%	30.0%	65.0%	1.0%	0.0%
Wakabayashi et al. (2006)						
Science Majors	894	19.5%	20.1%	43.1%	12.6%	4.7%
Humanities Majors	867	3.2%	9.5%	49.7%	22.8%	14.8%

The question remains if these differences in systemizing and empathizing thinking have anything to do with e SBL curriculum satisfaction. A correlation analysis between SQ, EQ and SQ-EQ scores and the eSBL curriculum reveals no significant relationships. However, there was a significant positive correlation between SQ score and career intent for "founding a business" post the eSBL curriculum ($r = +.24$, $p = .00$) and for "working for a small business" ($r = +.21$,

p = .00). SQ score also had a positive correlation with business skills self-efficacy following the eSBL curriculum (r = +.32, p = .00), which may indicate that students with strong systemizing skills may find the business challenges inherent in entrepreneurship more appealing that students with strong empathizing skills.

Predicting Entrepreneurial Intent – We are interested in understanding the curricular interventions and students' behaviors that could strengthen an engineering student's career intent for entrepreneurship. In this sample, career intent for "founding a business" had a significant positive correlation with a student's business skill self-efficacy post exposure to the eSBL curriculum, (r = +.36, p = .00). This makes sense in that students with a strong sense of their business skills probably bring a confidence to the challenge of entrepreneurship that makes it seems like an acceptable if not preferred career choice. The research question we asked is if any other variable might enhance this career choice.

To test this, we constructed two models, shown in Figure 10. Model 1 is simply the impact of business self-efficacy on entrepreneurial career intent, while Model 2 also includes overall satisfaction with the eSBL curriculum (which included the integrative thinking items), the Kolb learning style and the systemizing (SQ) and empathizing (EQ) scores of the individual student.

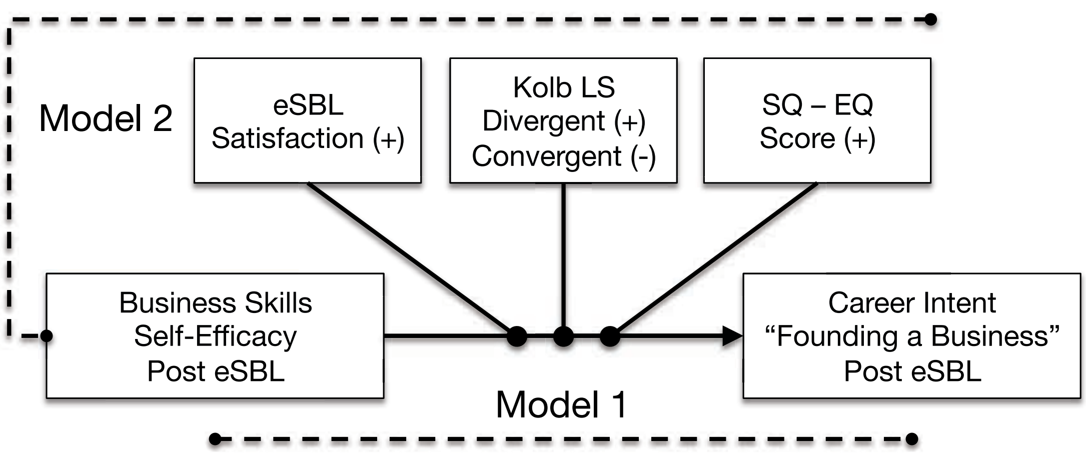


Figure 10 – Entrepreneurial Intent Learning Model

Multiple linear regression reveals that Model 2 explains twice as much variance in entrepreneurial intent relative to Model 1, as shown in Table 10. In total, Model 1 (business skill self-efficacy) explains 12 percent of the variation (r^2) in entrepreneurial intent. However, in Model 2 the inclusion of the student's satisfaction with the eSBL curricular approach, Kolb Learning Styles (specifically a higher score for divergence and lower score for convergence), and an SQ-EQ score that favors SQ increases the explained variance to 26 percent which is a medium-level effect size.[27] ANOVA comparison of the models shows this +14 percent point change in variance explanation Model 1 to Model 2 is significant, F (4) = 5.65, p = .00.

Table 10 - Multiple linear regression models predicting entrepreneurial intent

Predicting Career Intent: *"Founding a Business"*

Model – Variable (+/- Correlation)	***β***	**SE**	***t-value***	***p =***
Model 1 (Intercept)	1.34	.45	2.99	**.00***
Business Skills Self-Efficacy Post eSBL (+)	.54	.14	3.85	**.01***
Model Fit: Adjusted r^2 = .122				
Model 2 (Intercept)	-44.33	17.39	3.55	**.01***
Business Skills Self-Efficacy Post eSBL (+)	.62	.14	4.40	**.00***
Satisfaction with eSBL Curricula (+)	.45	.20	2.36	**.02***
Kolb LS: Divergent (+)	.50	.17	2.86	**.05***
Kolb LS: Convergent (-)	.44	.18	2.50	**.01***
SQ-EQ Score (+)	.03	.01	1.95	.05
Model Fit: Adjusted r^2 = .262				

ANOVA Model Comparison	**F**	**df**	**Adj** r^2	**Adj p**
Model 1	14.79	98	.122	**.00***
Model 2	8.04	94	.262	**.00***
Model 1:Model 2	5.65	4	+.140	**.00***

This indicates that business self-efficacy acquired through exposure to business concepts is a necessary precursor to changes in entrepreneurial intent, but not sufficient. This analysis would suggest that growing entrepreneurial intent among engineering students requires curricula that engage students in "social world" through integrative thinking. Integrative thinking encourages the student to synthesize information from multiple sources, to view problems from multiple perspectives and combine engineering problem solving with business decision-making - all objectives of the eSBL curriculum initiative. This curricular approach will probably have more success among students with a Kolb Divergent learning style, students who view concrete situations from many different points of view, prefer to work in groups, listening with an open mind and receiving personalized feedback.

7. Faculty Implementation Perspective

Both the scenario-based learning approach and the inclusion of business/entrepreneurial content are new in teaching a basic mechanics course. They both require "carving out" class and assignment time for topics beyond those traditionally covered. One might right ask, *what is lost?* Yes, some topics are lost in terms of coverage in that particular course, so one must carefully identify what are the key mechanics topics, concepts and procedures that are core to the course; these must remain.

This "inventory" is a useful exercise in its own right, since it is not unusual for topics to remain in a course for historical reasons and not as a representation of modern engineering practice or as critical to developing engineering thinking skills. This inventory for the course described here has resulted in a tighter (and leaner) set of mechanics ideas on which the course is based. This has allowed space for integration ideas like design and business to be included.

Introducing topics of design and business may be a stretch for some faculty teaching mechanics, as they may not be part of the faculty members' past and/or current work experience. It is true that faculty like to teach what they are expert in (which is generally a good idea). In the current course we have confronted this challenge in two ways. First, the teaching team partnered with an expert in business and entrepreneurship who was willing to act as a teaching coach. This coach helped prepare examples that are used in introducing the case stories in class by the instructors.

And second, the course teaching assistants have been engaged in these introductions, too, as some of them have recent experiences in start-ups from which to draw. Other ideas that could help faculty become more comfortable in including these design, business and entrepreneurship ideas in their courses would be additional teaching materials such as video examples of the case introductions (perhaps given by experts), and model rubrics for grading the business part of the lab assignments.

A final thought: adding eSBL to the course has added to the complexity of the course (e.g., adding a lab, helping students connect to ideas beyond traditional engineering, doing hands-on learning with a class of 100). More importantly, it has added tremendous energy to the classroom, as students' work (and argue) with one another about how to use the mechanics and business ideas to make well thought out (rational?) decisions on product direction.

8. Moving Forward

The objective of this research is to determine what is required to shift career intent toward entrepreneurship for the entry-level engineering student. Our experience with entrepreneurial scenario-based learning curriculum suggests that it requires more than simply incorporating entrepreneurial business skills into core engineering curriculum. It seems to require the engagement of divergent thinking skills that Kolb suggests involves "viewing concrete situations from many different points of view" combined with an integrated problem solving approach that encourages the student to synthesize ideas and frame problem solving in the context of real world business decisions. Finally, empathy plays a role, the ability to see the world through others perspective, although this roles is small and yet to be fully defined.

As for next steps, we intend to create three more scenarios for a total of six scenario-based learning curriculum examples. With these in hand, we intend to compare test results to a quasi-experimental (non-random) control experience and with engineering programs that represent a mix of large and small class size, and campuses with varying inherent degrees of interest in entrepreneurship among the student population.

It is also important to capture the role of faculty implementation. Both professors and teaching assistants should be asked their impression of the teaching experience, the ease (or difficulty) of incorporating entrepreneurship materials and any suggestions for improvement in the materials or process.

9. Acknowledgments

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eSBL Curriculum may be accessed at:
https://www.stanford.edu/group/design_education/cgi-bin/mediawiki/index.php/Madison_Longboard

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Mark Schar and Ruben Pierre-Antoine

Trek B-cycle
Designing a Drive Train

"… and starting in January 2008, Boulder will be the most bicycle friendly city in the United States!" proclaimed Mayor Shaun McGrath. With that, Trek's new program – B-cycle – was launched.

It is March 2007, in the west end of the Pearl Street Mall, downtown Boulder, Colorado. The Trek Bicycle Corporation and the city of Boulder are announcing the launch of the first urban-shared bicycle program in the United States. "Our mission is to help the world use the bicycle as a simple solution to complex problems," said John Burke, CEO of Trek Bicycles. "It can combat climate change, ease urban congestion, and build human fitness. It brings us together, yet allows us to escape. And it takes us places we would never see any other way. We look forward to working with the city of Boulder." Burke concluded to a round of polite applause, shook hands with the mayor and stepped off the speakers platform.

In the front row of city dignitaries sits Mike Post, the newly appointed Product Manager of Trek B-cycle. Mike graduated from Rose-Hulman Institute of Technology in 2003, with a Bachelor's Degree in Mechanical Engineering and a concentration in Manufacturing and Production Engineering. He was working for an exercise equipment manufacturer when he learned of an opening at his "dream company," Trek Bicycle. Mike came to Trek as a production engineer working on the "kids and cruiser" team while he learned the Trek business model, from part procurement to the retail stores. Mike showed an ability to thrive in a multi-functional team environment and when the B-cycle idea started to take hold at Trek, he jumped at the opportunity to lead it.

"January is just around the corner, you know," said John Burke sitting down next to Mike. Mike knew only too well how little time they had to launch B-cycle. They needed to make a decision about the all-important drive train components in two weeks, so parts could be ordered and production begin on the B-cycle bicycles. "I've got some ideas I want to share with you about the drive train design," said Burke. "Let's talk on the airplane on the way back to Madison."

Trek Bicycle Corporation and B-cycle -

Trek Bicycles was founded in 1976 by two friends, Dick Burke and Bevil Hogg, in Waterloo, WI and focused on making high-end steel bicycle frames to compete the then dominant Japanese and Italian manufacturers. From the very beginning, Burke believed in technology as the path to a better bicycle and over the years Trek has lead the development of molded carbon fiber frames, aerodynamic testing, compression suspension, the hybrid design bicycle, and the popular "y-frame." In 1997, John Burke, son of the founder Dick Burke, took over as CEO and dramatically increased the hiring of engineers to drive design. Today, Trek Bicycle is one of the largest and most respected manufacturers of performance bicycles in the world, with sales approaching $1B, marketing brands like Trek, Gary Fischer, Bontrager, Villiger and Diamant.

The concept of urban-shared bicycles as way to reduce traffic congestion and pollution has been around since the 1970's. The urban-shared bicycle concept involves bicycles that can be rented by the hour or day, checked out from docking stations using a pass or credit card and returned to another station when the rental is finished. Perhaps the highest profile urban-shared bicycle program is called *Vélib'*, a combination of the words *vélo* (bicycle) and *liberté* (freedom), operating in Paris, France. *Vélib'* was launched with much fanfare in 2007, and has quickly grown to 18,000 bicycles and 1,225 docking stations scattered throughout the city. The city of Hangzhou, China is also planning an urban-shared bicycle system of 66,500 bicycles and 2,500 docking stations. As of 2007, however, no significant urban-shared bicycle system existed in the United States.

John Burke embraced the idea of bringing urban-shared bicycles to the United States. In partnership with Humana (a heath-care company) and Crispin Porter + Bogusky (an advertising agency), Trek Bicycles launched a program called B-cycle, an urban-shared bicycle program for US cities. The B-cycle program was designed to take advantage of the internet, with internet connected docking stations, a reservation/drop-off system, smart-phone enabled searches of location availability as a well as flexible pricing from minute-by-minute rates, hourly rates, daily rates and even annual rental rates. Several cities expressed interest in the B-cycle concept, with Denver and Boulder, Colorado among the most interested.

Figure 1 - Artist sketch of the proposed B-cycle program (from right to left): the B-cycle bicycle with basket, the B-cycle logo and a solar powered B-cycle docking station.

The Tourist -

"Remember what we saw in Paris?' asked John Burke. Mike was sitting in the middle seat of the coach section, right next to his CEO, John Burke, as they returned from the Boulder launch. Burke always flew coach, not so much to prove a point but to stay connected with the people who used his products. "Sure, I remember seeing lots of tourists renting Vélib' bicycles," said Mike. Burke had arranged for a team of Trek managers to hang out for a week in Paris watching Vélib' bicycle stations, taking notes on who was renting and returning bicycles. The rule was that every fifth customer who rented a bicycle was approached for an interview with the help of an interpreter. They estimated about 40% of Vélib' customers were visitors to the city.

Figure 2 - Mike's sketch of a Tourist using the B-cycle

"Boulder has lots of tourists!" replied Burke, "And I'm thinking tourists should be our target customers for B-cycle in Boulder." Certainly, Boulder is a tourist town. With a population of a little over 100,000 (that includes about 25,000 students at the University of Colorado Boulder), the Chamber of Commerce estimates that the city hosts about 150,000 visitors each year. "And our economic data suggests that tourists will spend about $20 per day renting a bicycle and they are easy on the wear and tear. The big concern is stations. We'll need to have more stations to make pick up and drop off easier," continued Burke.

While they are talking, Mike is taking notes and sketching in his notebook. This is a habit he picked up in college, in a design class, where he learned that sketching by hand was a way to engage thinking that otherwise might not become evident. As he thought about a tourist as the primary customer for B-cycle, he sketched his impression of a tourist.

The Bicycle Drive Train -

Bicycles began to be considered serious human-powered transportation devices about the mid-19th century. These bicycles were direct powered, meaning the crank and pedal were directly attached to the wheel, so one turn of the crank resulted in one turn of the bicycle wheel. In the 1890's, gears and a drive chain were introduced to bicycle design and this remains essentially the drive train for modern bicycles.

The bicycle drive train consists of four major components – chainring, cassette, derailleur and the drive chain – as shown in Figure 3. Bicycles have a special kind of gear called a **sprocket**. Sprockets convert rotational energy into mechanical work though a chain rather than meshing directly with other gears. The sprocket (or sprockets) attached to the pedal called the chainring, while the sprockets attached to the rear wheel are called the cassette. The chainring and cassette are connected with a chain and the rider pushes on the pedal, turning the crank and rotating the chainring. This pulls the chain forward rotating the cassette and rear wheel. The derailleur shifts the chain location to individual sprockets.

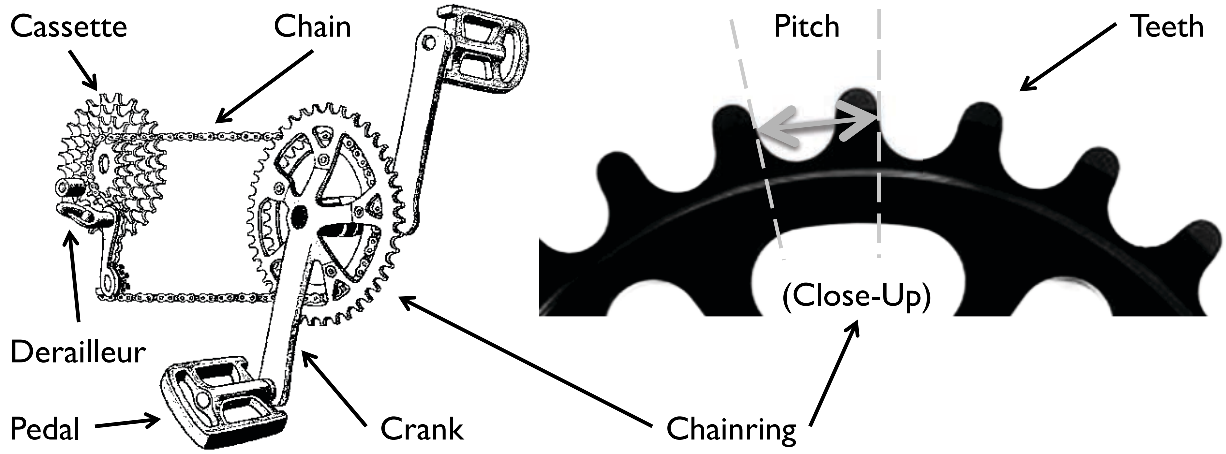


Figure 3 - The Bicycle Drive Train with an overview of the key components (left) and a close-up view of the chainring (right)

Each sprocket has a specific number of teeth around its circumference (larger sprockets have more teeth than smaller sprockets). The pitch of all teeth must be matched exactly to insure that the chain smoothly transfers the power generated by the chainring to the cassette. With equal pitch, counting teeth on a sprocket becomes a quick way to compare the circumference of various sprockets. On a bicycle, the chainring, cassette and drive chain are sold as a set and cannot be "mixed and matched."

The bicycle drive chain is influenced by the intended use of the bicycle because it defines both the **speed ratio (SR)** and the **mechanical advantage (MA)** of the power system. The speed ratio is a measure of how many turns the rear wheel will make with one turn of the crank. A higher SR, say 2.5, says that for every turn of the crank the rear wheel will turn 2.5 times; given a constant pedal rotation, a bike will go faster with a higher SR. Mechanical advantage is a measure of how power from the rider transfers from the pedal to the wheels through the drive train. MA takes into account the crank size, wheel diameter, chainring size and cassette size. A higher MA means more force to the rear wheel, while a lower MA means less force. The trade off is speed, with a higher MA comes lower SR while a lower MA means higher SR. This balance between force and speed is an important design choice for any bicycle engineer.

The Commuter -

"Let's grab some lunch and you can tell me about the Boulder launch," said Steve Malchin, Trek's VP of Engineering Operations, while leaning over Mike's work cubicle wall. Mike and Steve are good friends and avid road racers. One of the perks of working at Trek is that you get to "demo" the latest bike designs, usually designs headed for the Tour de France, and it was not unusual for Mike and Steve to do 150 km of road racing through the Wisconsin countryside on any given Saturday.

"I think the launch went well; they are certainly behind this 100%," said Mike putting down his tray in the company cafeteria. "We've got a lot to do on our side to get ready for January." "No kidding," replied Steve, "have you made the drive train decision? I've got to get the suppliers lined up." "Not yet, we're still talking about it," returned Mike. "John put a sales pitch on me about focusing on tourists and it seems to make a lot of sense."

Figure 4 - Mike's sketch of a Commuter using a B-cycle

"Sure, sure, but there are other options," said Steve. "Remember, Trek is a performance bicycle company built through engineering. It would be a shame if we compromised on the specifications." "What do you mean … compromised?" asked Mike. "We know about durability, we know about light weighting and we know about drive trains," continued Steve. "It would be a shame if we built the B-cycle in a way that doesn't take advantage of this know how." Mike took out his notebook and began to write.

"I'm thinking we build a bike that can stand up to the pounding of an everyday commute. As you know, bicycle commuters are a dedicated bunch, they are fitter than average, want to get from Point A to Point B as efficiently as possible and appreciate a well-engineered bicycle. And bicycle commuting is the future; B-cycle is our way to put a dent in the universe. Let's not waste it on inferior bicycle specifications."

"Oh, and one last point … it makes good economic sense to focus on commuters," continued Steve. "They are regular users, which means big revenue. Say we charge $5 per day. A commuter will use that bicycle 200 days per year, which is $1,000/bicycle of revenue. Once we have them in the franchise we don't have to spend as much marketing money to attract users, even more help to the economics. Think about it … and pass the ketchup."

Bikes Belong Coalition -

Mike returned to his office after lunch still thinking about what Steve had to say. "$1,000 of revenue per bicycle per year is hard to ignore," he thought. Still, there were pieces missing from the puzzle. Who were tourists, who were commuters, and what were their usage habits? Mike remembered he had met Tim Blumenthal, President of the Bikes Belong coalition (www.bikesbelong.org) at the Boulder launch. Bikes Belong is a non-profit, industry advocacy group working to change public policy in a way that promotes bicycle riding and creates safe places to ride. Mike pulled Tim's business card out of his notebook and dialed the phone.

"Yes, we have that data," said Tim, "we had some interns at CU Boulder collect it last summer." Mike called Tim asking if they had any data on bicycle ridership in Boulder that might be helpful. "We outfitted bikes with GPS trackers and followed the usage patterns of about 50 riders, then followed up with about a dozen interviews. The data showed some real differences." "Like what?" asked Mike. "Well, there are definitely some people that use shared bicycles to get to work. They pick up the bicycle in the morning; drop it off in the evening. On average, they travel about 12 km one-way and they are on the bike for 30 minutes per trip." "That's pedaling at a pretty good clip," added Mike.

"There is a second group that we call the 'casual user' or 'visitor'," continued Tim. "These folks would pick up and drop off the bicycle through out the day, mostly traveled downtown and out to campus. They would only go about 10 km the entire day and be on the bike moving an average of 90 minutes." "Thanks, this is helpful," said Mike.

"Oh, and one other thing. We've had some changes here in Boulder that weren't captured by this study," said Tim. "The downtown merchants have funded a new parking lot on the perimeter of the downtown shopping area in an effort to get cars off the street. They want the spaces for a pedestrian mall and for special events. They are considering a shuttle bus, but we'd like to see them use B-cycles. The new parking lot is an 8 km round trip and we think anything less than 40 minutes of biking time would compete with riding a bus shuttle."

Cycling Research Center –

Trek Bicycle is an engineering-oriented organization and nothing speaks louder to engineers than data. The world of professional cycling has ushered in a new era of performance measurement and one of the leaders in this field is Dr. Mikel Zabala, Director of the Cycling Research Center - CRC (www.cycling-research.com) in Granada, Spain. Mike had heard a presentation by Dr. Zabala on "power measurement through telemetry" at a recent industry-event and decided to make contact through email. After a few exchanges, they agreed to talk over Skype.

"You can call me Mike, Mike," joked Dr. Zabala. After a discussion of the B-cycle project and the capabilities of the CRC, Dr. Zabala began, "most of our data was generated by the performance cyclist, but we do have some data on the casual cyclist that might be helpful." The CRC had done a study with the Dutch government examining levels of bicycle physical fitness and something they called "rider comfort." The rider measured "comfort" in real-time with a turn knob on the handlebars while drive train settings, speed and distance data were collected as shown in Table 1. Dr. Zabala added data on the professional cyclist.

	Heartbeat (BPM)		Cadence (RPM)		Drive Train (MA)	
Rider Type	**Max Rate**	**Average**	**Max Rate**	**Average**	**Max**	**Average**
Professional	185	135	110	85	N/A	.08
Amateur	165	125	90	70	.10	.15
Casual	130	90	70	55	.15	.25
Non-Rider	110	80	50	40	.25	.40

Table 1 - Rider "comfort" data supplied by Dr. Zabala at the Cycling Research Center

Heartbeat was measured as beats per minutes as a maximum for the ride and average over the ride. Cadence is a term for the rate of one full turn of the crank and is measured in revolutions per minute (RPM). Target cadence was the average while the rider was in the "comfort" zone, while max cadence was the peak rate before the rider began recording "distress." The drive train mechanical advantage (MA) is determined by the gear settings while the rider was in the "comfort" zone. As MA drops, Max Rate is the threshold for dropping out of the "comfort" zone.

"Oh, and one more point," continued Dr. Zabala, "we found that the better the cyclist, they higher the cadence and the more they showed a preference for a shorter crank length. It seems that at high cadence, it's easier to turn a shorter crank even though it has an impact on mechanical advantage." "Thanks Dr. Zabala, er Mike," said Mike. "I think these data will useful in our analysis."

The Shopper -

"Got a minute?" asked Keith van Hooten leaning over Mike's cubicle wall. "For you, I've always got time!" replied Mike. Keith is the Chief Design Engineer at Trek Bicycles and has been with Trek for 25 years, over half the time the company has been in existence. Keith influences every significant design produced by Trek. "You're getting it from all sides, aren't you?" chuckled Keith. "No kidding," agreed Mike.

"We got into the urban shared bicycle market because we want to make an impact on the world," started Keith as he settled into a chair next to Mike's desk. "And the more we get people to make bicycle riding a part of their everyday life, the closer we move to that goals." "I couldn't agree more," said Mike, "and that's why I'm leaning toward to the bicycle commuter as our B-cycle customer. They use a bicycle everyday and generate a consistent and significant stream of revenue."

"Spoken like a product manager!" said Keith. "What you say is true, but what worries me is that for the money they would spend on B-cycle they could buy their own bicycle. We'd be happy with that because they'd probably buy a Trek, but it's not very good for B-cycle." "I see you point," said Mike, "but I'm having a hard time thinking B-cycle is only a program for tourists. The market is too transient." "I couldn't agree more, although I know John sees it differently," replied Keith. "I've got a different direction for you – the shopper." Mike pulled out his notebook.

"You talked with Tim at the Bikes Belong coalition. Boulder is working on a new design of their city center. They want the cars out, and bicycles in," said Keith. "It's an intriguing thought," returned Mike, "but my concern is that if we design this for shoppers, almost by default, we exclude the other groups. The bike would be too hard for novice biker or tourist to operate and not fast enough for a commuter." "Maybe," said Keith, "and maybe not. Look over the drive train specifications. Perhaps there is a choice that works for a shopper and is still acceptable to other customer types." "OK, will do," said Mike. "I've got to get our drive train decision to Steve in two days, so it's time to crunch some numbers." "And I'll help you sell John, whatever you decide," offered Keith. "Deal!" agreed Mike.

Figure 5 - Mike's sketch of a Shopper using a B-cycle

Empathy Mapping and Personas -

As Keith stood up to leave, Mike turned to face his laptop. His head was swimming with data, advice and ideas. It was not clear what to do next, and abruptly he remembered the "sightless spoon." When he was a junior at Rose-Hulman, his ME120 engineering design class won an E-Team grant from the NCIIA (National Collegiate Inventors and Innovators Alliance) to develop a training spoon for sightless children. The sightless spoon used haptic feedback provided by small bumps on the indicator shaft to teach the child's hand when the spoon is tipped too far in one direction.

As part of the grant, his design team attended an E1 VentureLab seminar to help them refine their design and grant proposal. At the seminar the instructor introduced the concept of "Empathy Mapping." Empathy is the ability to recognize the emotions of another person, and these emotions influence the products they want and how they use those products. An empathy map is a method a designer uses to identify emotions, categorize them in a useful way and use this information to generate design ideas. The first step in building an empathy map is developing a "persona" or conceptual statement of the user of a design. Designers often begin the persona development process with a rough sketch of the target user, using this as a way to capture thoughts that are not easily expressed in words.

Suddenly, Mike remembered that he had been sketching personas in his notebook throughout the past week as he took notes on the various potential customers for B-cycle. He reached for his notebook and began to leaf through the pages looking over his drawings and notes. The personas he had sketched would not specifically answer the question of which drive train to specify for B-cycle, but it was at least a way to frame the discussion.

The Options -

As Mike was looking at his notebook, his laptop beeped and he looked up to see an email from Steve Malchin titled "B-cycle Drive Chain Options." Mike opened the email and it began …

Mike –

I've been working with our supplier team on possible drive train components for B-cycle. We have already agreed to use the Bontrager 26x1.5 tire and (660mm outer diameter). Below is a brief description of the options available.

B-cycle Drive Chain Options:

1. ***Shimano Traveler*** *– Shimano is our most reliable supplier with an excellent of reputation for reliability. The Traveler drive train is a 30-28/24/22 (chainring teeth – cassette gear teeth) with a 170mm crank length.*
2. ***Campagnolo Trieste*** *– The top Italian supplier who has made an aggressive price offer. The Trieste drive train is a 48-34/28/24 with a 170mm crank length.*
3. ***SRAM Cardinal*** *– SRAM supplies the top-end crank sets for our mountain bikes. The Cardinal drive train is a 52-24/20/16 with a 160mm crank length.*
4. ***Shimano Blue*** *– This is a new offering from Shimano and they think it's the best drive train they offer. The Blue drive train is a 52-32/24/18 with a 170mm crank length.*
5. ***Bontrager/Rohloff*** *– This is an out-of-the-box option. Rohloff is a quality supplier of internal gear hubs, so there would be only one gear on the cassette and shifting happens inside the hub. We'd pair this with our Bontrager 44-tooth chainring and 170mm crank length. The Rohloff has a 26 tooth external gear with a +/- 15% on mechanical advantage of the other two gear settings. This could be a good option.*

Let's set up a meeting for tomorrow and you can take the team through your thinking. Later … Steve

Bike Lab Worksheet

In Class

Trek B-cycle
Designing a Drive Train

Your Name: (first and last)

____

Your Lab Teammates: (first and last names)

____

____

____

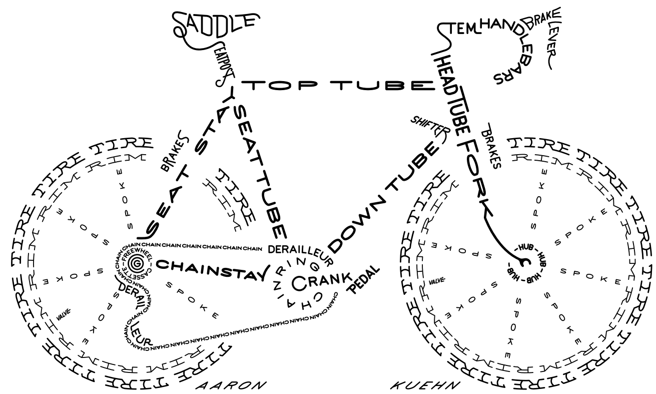
Your Pod: (circle)

♠ ♥ ♦ ♣

Part 1: Bicycle Overview

Draw a line from the Bicycle Part to its location on the Bicycle.

Rear Derailleur ◎
Cassette ◎
Spoke ◎
Rear Wheel Rim ◎
Rear Wheel Tire ◎



◎ Chainring
◎ Chain
◎ Crank
◎ Pedal
◎ Chainstay
◎ Front Derailleur

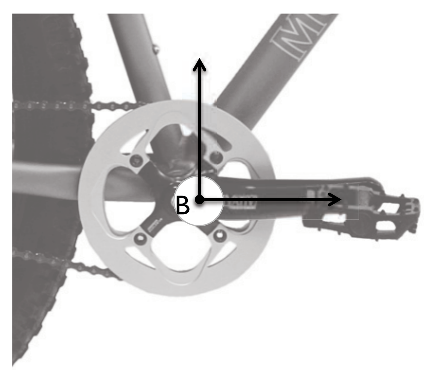
Part 2: Free Body Diagram:

Label and Draw forces over each picture below that illustrates the drive train forces.

Cassette – Rear Wheel

Label: F_{AX} and F_{AY}
Draw: F_{chain} and $F_{friction}$

Chainring – Front Wheel



Label: F_{BX} and F_{BY}
Draw: F_{chain} and F_{foot}

Part 3: Measuring Your Bicycle

Place your bicycle on a table (seat and handle bars down, wheels up) and fill out the chart below:

Manufacturer

Brand

Rear Wheel Radius
(axle to outer tire edge)
__________ mm

Crank Length
(center of drive shaft to pedal pivot)
__________ mm

# Gear Teeth			
Cassette – Rear Wheel		**Chainring – Front Wheel**	
largest gear		largest gear	
smallest gear		smallest gear	

* if applicable

Grader Space
1
2

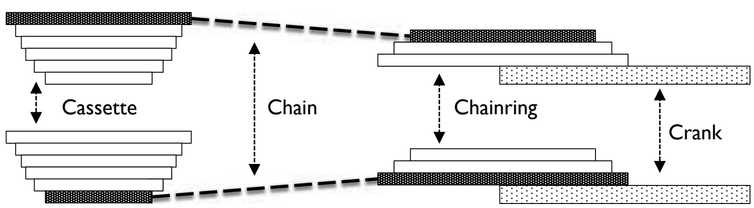
Bike Lab Worksheet

In Class

Part 4: Calculating Speed Ratio

The speed ratio describes the relationship between the crank gears and the cassette gears connected by the chain. It defines the number of rotations of the rear wheel for each rotation of the crank.

"Low Gear": Smallest Chainring, Largest Cassette (Top View)



"High Gear": Largest Chainring, Smallest Cassette

Speed Ratio • Eqn(1)

$$Speed\ Ratio = \frac{\omega_{out}}{\omega_{in}} = \left(\frac{N_{chainring}}{N_{cassette}}\right)$$

Mechanical Advantage • Eqn(2)

$$M.A. = \frac{F_{out}}{F_{in}} = \left(\frac{L_{crank}}{R_{wheel}}\right)\left(\frac{N_{cassette}}{N_{chainring}}\right)$$

Turn your bicycle over and place it on a table so it rests on the seat and handle bars. Set your bicycle to "low gear" (smallest chainring, largest cassette gear), turn the crank exactly 5 full rotations and count the number of rotations of the rear wheel. Record your answer to the nearest 1/10th rotation in the chart below using the "low gear" line. Hold the wood block against the wheel to create light resistance; note your impressions below.

Next, set your bicycle to "high gear" (largest chainring, smallest cassette gear). SLOWLY turn the crank 5 full rotations and count the number of rotations of the rear wheel by watching the tire stem. Record your answer to the nearest 1/10th rotation below using the "high gear" line. Hold the wood block against the wheel to create light resistance; note your impressions.

	Observation		**Calculation**				
Gear State	(1) Observed # Rear Wheel Rotations (5 crank turns)	(2) Difficulty to resist rotation (hard/easy)	(3) Chainring (# teeth)	(4) Cassette Gear (# teeth)	(5) Speed Ratio (Eqn 1)	(6) Calculated # Rear Wheel Rotations (5 crank turns)	(7) Difference: Observed - Calculated (1) – (6)
Low Gear							
High Gear							

Now, calculate the Speed Ratio (5) by using the number of teeth in the chainring (3) and cassette gear (4) for each gear state and using Equation (1) from Part 4. From this, calculate the number of wheel rotations for 5 crank turns (6), and then compare your observed wheel rotations to your calculated wheel rotations (7).

Speed ratio can also be used to calculate distance traveled. Calculate how far the bicycle would travel with 5 crank turns in low gear and 5 crank turns in high gear. Remember, the circumference of a wheel is $2\times\pi\times wheel\ radius$.

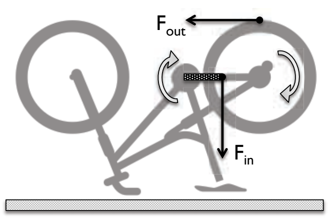
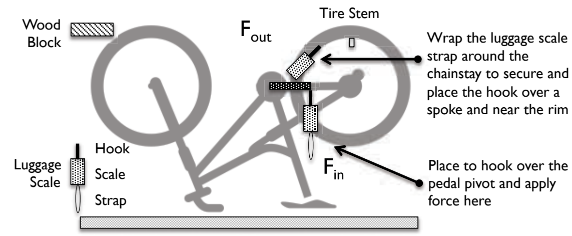
Hint: Calculate the distance traveled for one wheel turn and multiply it by the number of wheel turns for each gear state. ($\pi = 3.14159$)

	Distance Traveled 5 crank turns
Low Gear	meters
High Gear	meters

Bike Lab Worksheet

In Class

Part 5: Calculating Mechanical Advantage

Summary of Forces	Instructions	Lab Set-Up
	Place the bicycle on a table upside down.	

Mechanical advantage (MA) is a measure of the force amplification. On a bicycle, force is imparted on the pedal by the rider (F_{in}) and reduced because the crank length is only about ½ the radius of the rear wheel. The gears amplify force (F_{out}) based on the ratio of cassette gear to the chainring. The combination of the crank length, wheel radius, cassette gear and chainring define the mechanical advantage (MA).

Set your bicycle to "low gear" (smallest chainring, largest cassette gear), set the crank to a horizontal position as shown above in Part 4. Attach a force gauge (luggage scale) to the pedal pivot post with the hook to measure "force" input. Use a second force gauge and wrap the strap around the changestay to secure the gauge, while placing the hook over a spoke as near to the rim as possible. Tare both gauges and apply 4 kilograms of force (F_{in}) on the pedal; record the force (F_{out}) on the gauge attached to the rim in the chart below [(1) and (2)].

Next, set your bicycle to "high gear" (largest chainring, smallest cassette gear) and repeat the experiment. Record the force (F_{out}) on the gauge attached to the rim in the chart below. Now, count the number of teeth in the chainring (4) and cassette gear (5) for each gear state. Record the crank length from Part 3. Calculate the mechanical advantage (8) of your bike in low gear and high gear using Equation (2) in Part 4. Find the difference (9) between your observed value and calculated value.

	Measured		**Calculated**						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Gear State	Pedal Force (F_{in}) (kilograms)	Wheel Force (F_{out}) (kilograms)	Observed MA (F_{out})/ (F_{in}) (2)/(1)	Chainring (# teeth)	Cassette Gear (# teeth)	Crank Length (mm)	Wheel Radius (mm)	Calculated MA Eqn (2)	Difference: Observed - Calculated (3)-(8)
Low Gear									
High Gear									

Part 6: Summary - Let's pull it all together …

Which gear state has a higher Speed Ratio? In other words, which yields more wheel rotation for each turn of the crank?	Low Gear	High Gear
Which gear state has a higher MA? In other words, which applies more friction at the wheel for the same input?	Low Gear	High Gear
Which gear state is good for going uphill?	Low Gear	High Gear
Which gear state is good for going fast on flat roads?	Low Gear	High Gear
Can a gear state have both higher MA and more rear wheel rotation than all the others?	Yes	No

Why/Why Not?

What might explain differences in the calculated and measured values of MA and Speed Ratio?

Bike Lab Worksheet

In Class

Part 7: Empathy Notes and a Persona *(discuss in Teams, write individual notes)*

Empathy notes are the designer's way of "getting inside" the motivations of the design customer. This provides input to the development of an empathy map. Empathy maps are not a rigorous, research-based process, but it can quickly get a group to focus on the most important element: the customer.

Product designers often create "personas" to help them think about design. A persona is a description of a person for whom the design is intended. Personas are often displayed in the form of an empathy map that helps summarize learning, compare and contrast different potential design targets and ultimately focus design decisions.

Record your empathy notes below, describing what you have learned about potential customers of B-cycle – the Tourist, the Shopper and the Commuter. Some data can be found in the case study and some information is your opinion about what might be important to a particular type of B-cycle customer. Work in a group and discuss your thoughts – it is not necessary that you all agree.

Empathy Notes

Persona:	**Tourist**	**Shopper**	**Commuter**
What problem is each persona trying to solve?			
Pains – what PAIN are each persona trying to avoid?			
Gains – what GAIN are each persona trying to achieve?			

Bike Lab Worksheet

Homework

Your Name: (first and last)

____

Your Pod: (circle)

♠ ♥ ♦ ♣

Part 1: Profile of an Ideal Trip

Review the data on an "ideal trip" for each persona, calculate speed (3), wheel rotations (4) and rear wheel RPM (5).

Persona	Ideal Trip from Case Study		Calculate			From Case Study	
	Distance kilometers	Time minutes	Speed k/h	Rear Wheel Total Rev.	Rear Wheel RPM	Ideal Pedal RPM	Min Comfort Mech Adv
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Tourist	10	90				40	0.40
Shopper	8	40				55	0.25
Commuter	12	30				70	0.15

Hint: Wheel diameter is 660mm (.66 meters); π = 3.14159

Part 2: Analyze the Drive Train Options

Calculate speed ratio (12), pedal RPM for an ideal trip (13-15) and mechanical advantage (16) for each drive train option.

Speed Ratio - Equation 1

$$Speed\ Ratio = \frac{\omega_{out}}{\omega_{in}} = \left(\frac{N_{chainring}}{N_{cassette}}\right)$$

Mechanical Advantage - Equation 2

$$M.A. = \frac{F_{out}}{F_{in}} = \left(\frac{L_{crank}}{R_{wheel}}\right)\left(\frac{N_{cassette}}{N_{chainring}}\right)$$

Hint #1: Pedal RPM is the rear wheel RPM divided by the speed ratio.
Hint #2: This is a good use for a spreadsheet!

Option	From Case Study				Calculate – Ideal Trip				
	Manufacturer Brand	Chainring teeth	Cassette teeth	Crank Length mm	Speed Ratio Equ 1	Tourist Pedal RPM	Commuter Pedal RPM	Shopper Pedal RPM	Mech Advantage Equ 2
	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
1	Shimano	30	28	170					
	Traveler	30	24	170					
		30	22	170					
2	Campagnolo	48	34	170					
	Trieste	48	28	170					
		48	24	170					
3	SRAM	52	24	160					
	Cardinal	52	20	160					
		52	16	160					
4	Shimano	52	32	170					
	Blue	52	24	170					
		52	18	170					
5	Bontrager	44	-15%	170					
	Rolhoff	44	26	170					
	(Internal)	44	+15%	170					

Bike Lab Worksheet
Homework

Part 3: Putting It All Together

Decide on your design persona (17), then recall the ideal pedal RPM (18)(6) and minimum comfort mechanical advantage (19)(7) for this persona. Review your data from Part II, then select a manufacturer and brand (20) that is best for your design persona. Record the ideal trip RPM (21) for this drive train choice (Part II, 13-15) and calculate the difference (22) from the Ideal RPM (21-18). Finally, record the mechanical advantage (23) for this drive train choice (Part II, 16) and calculate the difference (24) from the design persona minimum comfort mechanical advantage (24-19).

Design Persona			Your Drive Train Choice				
What persona are you designing for?	Ideal Pedal RPM	Min Comfort Mech Advantage	Manufacturer/ Brand	Ideal Trip Pedal RPM	Difference vs Ideal RPM	Mechanical Advantage	Difference vs Min Comfort Mech Advantage
(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)

Part 4: Making it Real

Designers often sketch or draw a representation of the customer of their design. This is a way for your brain to integrate thoughts that are often hard to express in words.

Try it! Draw a picture (right) of the type of customer you think should be the target of this design – Tourist, Shopper or Commuter. Add notes on the persona that you think are important and should be considered as part of the final design.

Bike Lab Worksheet

Homework

Part 6: Enrolling Your Team
Empathy Maps (right and next page) can be used to bring team members together around a vision of the design customer. Matt will need to enroll his team on the drive train decision and will use an empathy map.

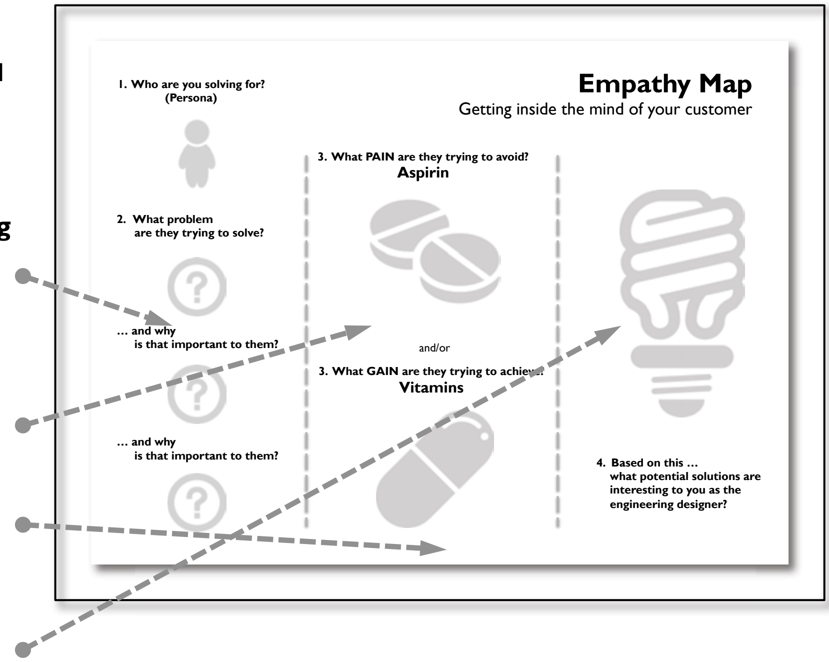
What problem is your persona trying to solve with B-cycle?

Why is that important to your persona?

What PAIN are they trying to avoid by using a B-cycle?

What GAIN are they trying to achieve with B-cycle?

Based on this, are there any design characteristics that are critical to make B-cycle the best solution for your design persona?



Now, try working with an Empathy Map to capture your ideas. On the following page is a full-size Empathy Map. Write or sketch your thoughts – *who are you solving for? What problem are they trying to solve? What PAIN are they avoiding or GAIN they are achieving?* and *what are the potential solutions that most interest you as a designer?* Now imagine how Matt might use this to talk about his design decision with the broader product development team at Trek.

Empathy Map

Getting inside the mind of your customer

**1. Who are you solving for?
(Persona)**

**2. What problem
are they trying to solve?**

**… and why
is that important to them?**

**… and why
is that important to them?**

3. What PAIN are they trying to avoid?
Aspirin

and/or

3. What GAIN are they trying to achieve?
Vitamins

**4. Based on this …
what potential solutions are
interesting to you as the
engineering designer?**