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Effect of a Project-Based Learning Activity on Student Intrinsic Motivation in a Biomechanics Classroom

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Abstract:

Project-based learning, such as model eliciting activities (MEAs), enhances student understanding and problem solving in the engineering classroom, but its effect on student motivation is less understood. Therefore, this objective of this work was to determine if the use of a MEA versus traditional homework in a biomechanics classroom would enhance student intrinsic motivation. A MEA based on designing a simplified hip replacement prosthesis was developed and implemented in an introductory biomechanics classroom consisting of 2nd and 3rd year bioengineering students. After introducing the problem, students defined important assumptions, equations, and parameters for their simplified hip implant. After reviewing the necessary assumptions and equations, students modeled a hip implant by implementing basic static equilibrium and strength of materials equations in Microsoft Excel and wrote a memo to communicate their results. After submission of the project, students filled out a post-activity questionnaire online (Qualtrics) to survey their motivation. Questions were designed to assess motivation based on competence, autonomy, purpose, community, and appreciation for both the MEA and traditional homework using a Likert scale (12 questions each). Additionally, students ranked five items representing autonomy, community, purpose, competence, and extrinsic forms of motivation in order of importance. Survey data was analyzed using a Wilcoxon Signed Rank test to compare average responses between the MEA and homework (significance at $p < 0.05$), and a Friedman ANOVA was used to compare student rankings with a post-hoc Wilcoxon Signed Rank test using Bonferroni correction (significance at $p < 0.005$). Correlations between question scores were made using Kendall's Tau-b. Of the 12 questions on the questionnaire, 3 were significantly different between the MEA and homework. Specifically, students found the MEA to be more frustrating, had more choice in how to complete the MEA, and felt the MEA better related to their career goals. When ranking items, competence, purpose, and extrinsic motivation were ranked significantly higher compared to community and autonomy. Correlations indicated that students enjoyed the project more when they learned the content ($\tau = 0.61$), that students who felt the MEA helped with problem solving skills saw more "real world" application ($\tau = 0.61$), and that students who felt the MEA helped them learn the content also best understood the expectations for the project ($\tau = 0.54$). Although students found the MEA to be more frustrating than traditional homework, they also felt they had more choice in how to complete the assignment (i.e. autonomy) and that it was more related to their career goals (i.e. purpose). Generally, 2nd year students desired less autonomy and were more frustrated than 3rd year students. Students responded that the least important motivators to them were autonomy and community, and so future iterations of the activity should target student competence and purpose. Overall, students showed higher motivation in key areas for the MEA compared to traditional homework, and therefore strategic implementation of MEAs to study biomechanics may assist to both improve student understanding and enhance motivation.

Introduction:

Student motivation has been shown to be a powerful tool for improving learning in the classroom[1]. Categories of motivation can be broken into extrinsic and intrinsic, each of which differentially contributes to the enhancement of student learning[2]. Extrinsic motivations are related to an outcome that is separable from deep learning of material, i.e. motivation to obtain a "good grade" on an assessment. Intrinsic motivations are those done for some inherent satisfaction, which can be grouped under senses of autonomy, community, purpose, and competence[3]. Whereas extrinsic motivations can be more "tangible" to students, intrinsic motivations have been shown to lead to deeper learning of material and better grades[4, 5]. In the engineering classroom, the development of life-long learners with deep understanding of engineering concepts is integral to the endurance of the engineering profession.

Over the past two decades, problem- or project-based learning has gained prominence as a recommended method to improve learning in the engineering classroom[6-12]. Techniques that focus on application of engineering concepts via simulated engineering problems in the classroom setting have been very effective in improving student understanding and deep learning compared to more traditional didactic means. In particular, project-based learning techniques have been applied in bioengineering classrooms in various forms (e.g. VaNTH STAR.Legacy Cycle) as a means of enhancing undergraduate curricula and improving how students learn bioengineering content[13-19]. Model Eliciting Activities (MEAs) in particular have been effective in enhancing student understanding and problem solving skills, as well as for developing important teamwork skills[20-24]. Throughout an MEA, students are required to work in teams and integrate various forms of conceptual knowledge to solve an open-ended, real-world engineering problem.

Although the role of MEAs in enhancing student learning has been previously demonstrated, it is unclear how effective MEAs are at improving student motivation. If model eliciting activities stimulate student intrinsic motivation in addition to improvement of student learning, the utility of MEAs as a tool to enhance deep learning and develop engineering students that are life-long learners can be further demonstrated. Therefore, this study sought to determine if the use of a project-based learning activity (i.e. MEA) in lieu of standard "plug and chug" homework assignments in a bioengineering mechanics classroom can enhance intrinsic motivation. It was hypothesized that students would report greater intrinsic motivation (in terms of autonomy, purpose, and learning community) for a project-based learning activity compared to a standard homework assignment.

Methods:

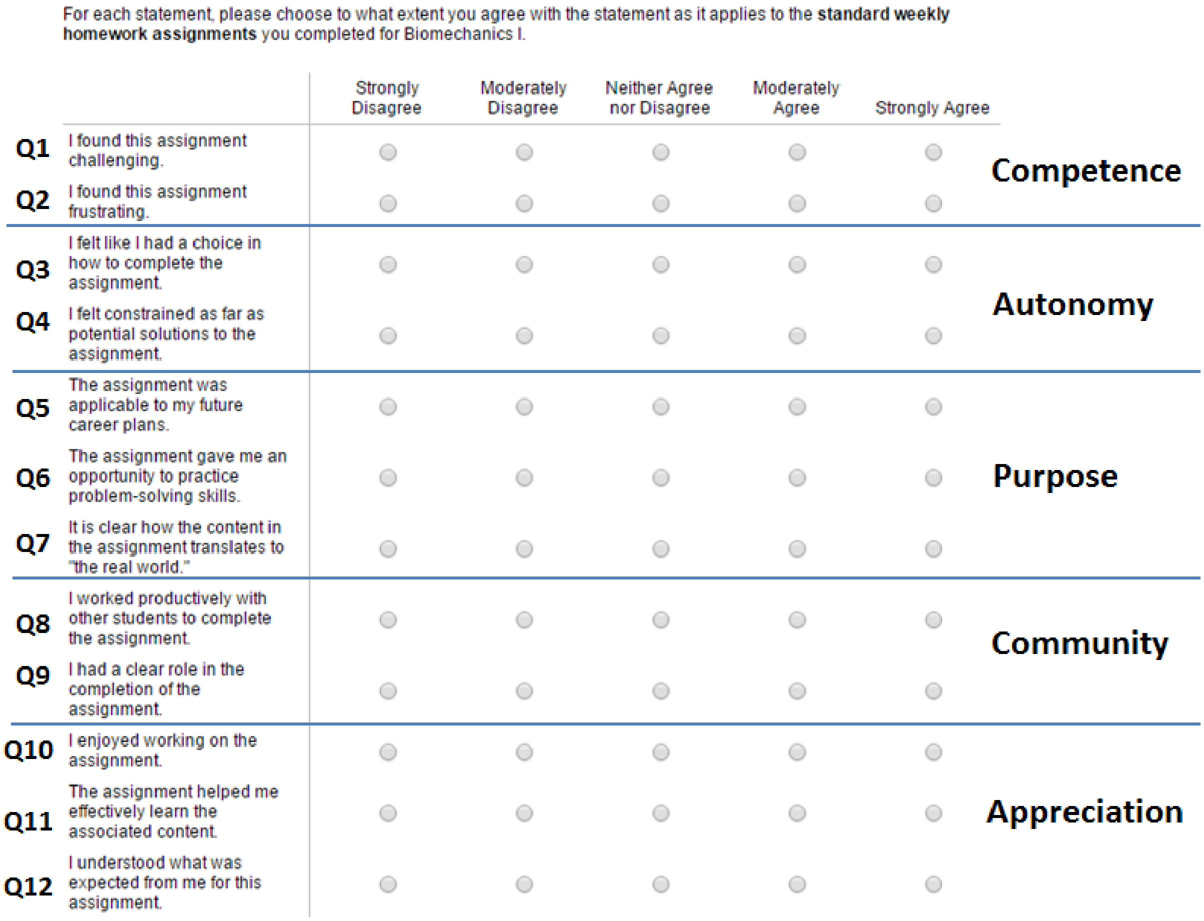
In order to investigate the effects of MEAs on student motivation, a new model eliciting activity was developed for implementation in an undergraduate biomechanics classroom. The MEA was designed for an introductory biomechanics course targeted primarily at junior bioengineering students, although the class also included sophomore and senior-level bioengineering students. The biomechanics course focused on teaching the basics of statics and continuum mechanics as applied to the human body, and featured topics related to assessing strength of materials for engineering design. Overall, the class consisted of 94 bioengineering students split between two class sections.

Considering the general goals and objectives of the biomechanics course, the MEA was designed around the problem of designing and evaluating a simplified hip prosthetic implant (Appendix A). Specific learning objectives that students should be able to accomplish while implementing the activity were as follows:

- Use solid mechanics equations to calculate strain and deformations resulting from beam bending and torsion
- Identify appropriate situations in which beam bending, torsion, and strain mechanics equations can be applied
- Design and evaluate a simplified hip implant that can withstand in vivo forces
- Write a report that communicates the findings of the hip implant model
- Sketch free body diagrams that illustrate the forces and moments acting on a solid body
- Explain the applicability of solid mechanics (specifically deformation/torsion/beam bending) to clinical situations

Students were required to complete the MEA in four steps (Appendix B). First, students individually answered a set of pre-activity questions that contextualized the project in "real world" terms and addressed concepts related to hip implant design. Along with this set of pre-activity questions, students were given a brief background lecture on hip implant design to introduce the nature of the open-ended question, and then were provided with a memo detailing the task for the MEA. After reading the memo, the class was broken into groups of five students to complete the first part of the activity. Groups were asked to write a response memo to define any assumptions (e.g. geometric and loading simplifications), equations (e.g. shear and normal stress, beam deflection, etc), and parameters (e.g. loads, material properties) required to design and assess their hip implant. Upon submitting the memo, a second short lecture was given to review important equations and parameters for designing the implant. Groups were provided with a second memo that provided important parameters to assess their models and requested the development of a spreadsheet tool (e.g. using Microsoft Excel) to predict and evaluate the function of hip implants with varied geometries. Based on the spreadsheet tool, groups were asked to write another memo with recommendations of minimum geometric dimensions and appropriate material properties for the implant, supported by findings from their developed model. Lastly, students were asked to individually answer a set of post-activity questions about hip implant design to reinforce important concepts from the project. All lectures and assessments were identical between the two class sections.

In order to assess student motivation after completing the activity, students were administered a post-activity online survey (using the Qualtrics platform). A set of 12 questions were designed using a Likert scale to assess motivation in five categories: competence, autonomy, purpose, community, and appreciation of the assignment (Figure 1). Students were asked to complete the same set of survey questions when considering both the hip implant design MEA and their standard weekly homework assignments (problem sets) completed for the course. Additionally, students were asked to rank how important five items representing autonomy, community, purpose, competence, and extrinsic motivation were to them in order to assess self-identified importance of different motivators (Figure 2).


For each statement, please choose to what extent you agree with the statement as it applies to the **standard weekly homework assignments** you completed for Biomechanics I.

		Strongly Disagree	Moderately Disagree	Neither Agree nor Disagree	Moderately Agree	Strongly Agree	
Q1	I found this assignment challenging.						Competence
Q2	I found this assignment frustrating.						
Q3	I felt like I had a choice in how to complete the assignment.						Autonomy
Q4	I felt constrained as far as potential solutions to the assignment.						
Q5	The assignment was applicable to my future career plans.						Purpose
Q6	The assignment gave me an opportunity to practice problem-solving skills.						
Q7	It is clear how the content in the assignment translates to "the real world."						
Q8	I worked productively with other students to complete the assignment.						Community
Q9	I had a clear role in the completion of the assignment.						
Q10	I enjoyed working on the assignment.						Appreciation
Q11	The assignment helped me effectively learn the associated content.						
Q12	I understood what was expected from me for this assignment.						

Figure 1: Post-activity survey questions were provided to students to assess their motivation related to competence, autonomy, purpose, community, and appreciation.

Survey response scores were compared between standard homework assignments and the MEA using Wilcoxon Signed Rank test (significance at $p < 0.05$). A Friedman ANOVA was used to compare rankings of motivator importance with a post-hoc Wilcoxon Signed Rank test using Bonferroni correction (significance at $p < 0.005$). Lastly, correlations between survey question scores and overall numerical grade on the assignment were made using Kendall's Tau-b, due to the large number of tied ranks.

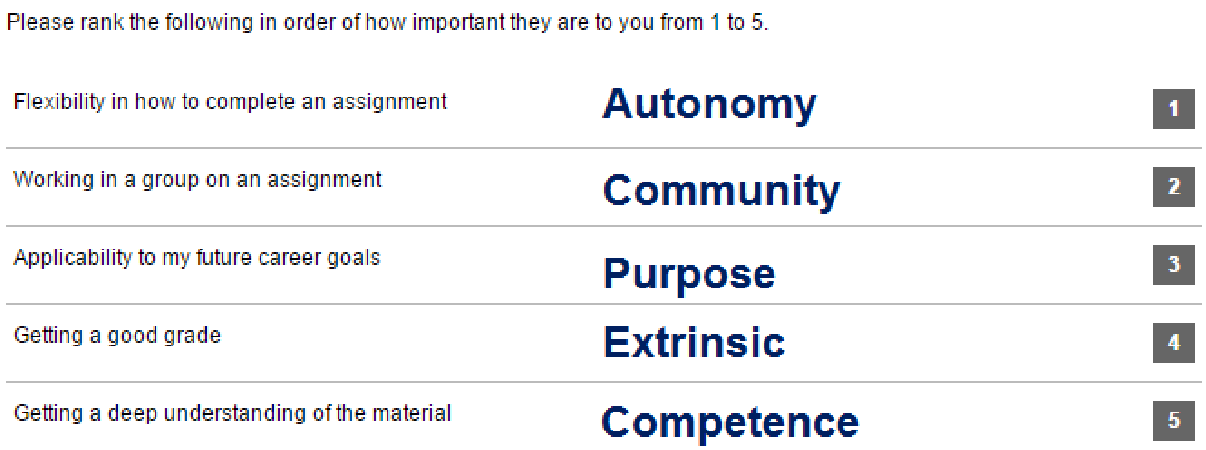


Figure 2: Post-activity survey question asking students to rank the importance of their personal motivators.

Results:

The average score on the assignment among all students was 89.6 ± 8.3% (out of 35 total points), and 84 out of 94 students completed all questions on the survey. Of the 12 questions that students answered on the survey, three showed a statistically significant difference between standard homework assignments and the new hip implant MEA (Figure 3). Specifically, students found the MEA to be more frustrating to complete compared to standard homework (Homework: 3.3 ± 0.1; MEA: 3.5 ± 0.1). However, students also felt that the MEA provided them with more choice in how to complete the assignment (Homework: 3.3 ± 0.1; MEA: 3.6 ± 0.1), and also felt that the MEA better related to their ultimate career goals (Homework: 3.3 ± 0.1; MEA: 3.5 ± 0.1). All other questions showed a difference of 0.1 or smaller between survey response scores. When ranking importance of motivators, students ranked competence, purpose, and extrinsic motivation significantly higher compared to community and autonomy (Figure 4). Overall, competence, purpose, and extrinsic motivators were statistically tied, with community and autonomy ranked over one point behind. Various statistically significant correlations were observed between survey responses for students, but only three of these showed at least a moderate strength of correlation ($\tau > 0.5$) (Table 1).

Table 1: Moderate Correlations Between Survey Questions

Survey Question	τ	p
"Practice Problem Solving" (Q6) vs "Real World Application" (Q7)	0.605	< 0.001
"Enjoyable" (Q10) vs "Learned Content" (Q11)	0.606	< 0.001
"Learned Content" (Q11) vs "Understood Expectations" (Q12)	0.543	< 0.001

Correlations between survey responses indicated that students who felt that the MEA helped them with problem solving skills also saw more "real world" application of the assignment (τ = 0.61), and enjoyed the project more when they felt they learned the content (τ = 0.61). Additionally, students who felt the MEA helped them learn the content also best understood the expectations for the project (τ = 0.54). Although various correlations were observed between survey response scores, the overall student grades on the project were not correlated with any of the survey response questions.

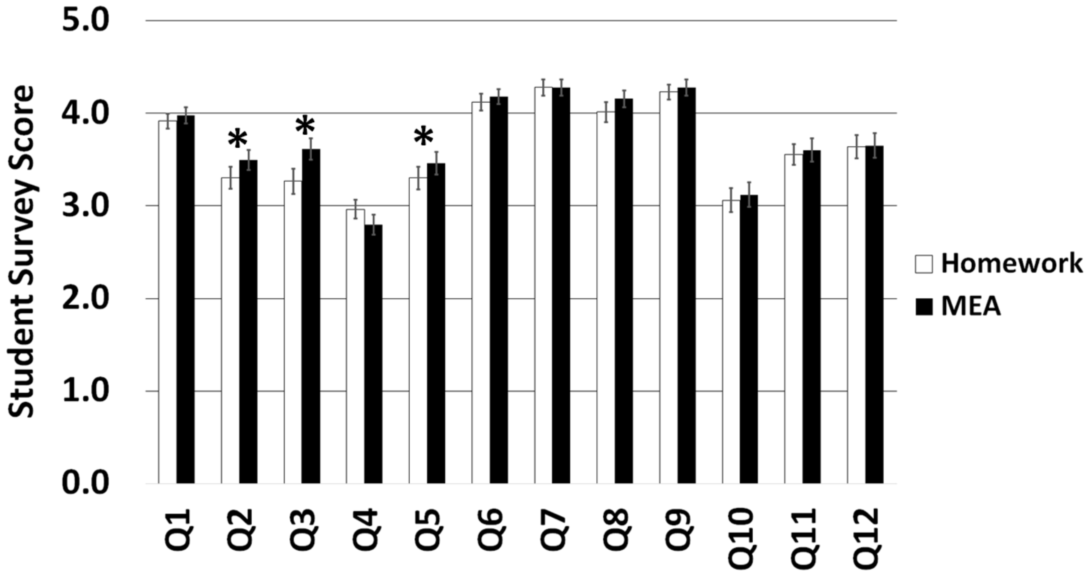


Figure 3: Comparison of student survey response scores for homework (white) and the MEA (black). Students found the MEA to be more frustrating than the standard homework assignments (Q2), but they also found they had greater autonomy in how to complete the MEA (Q3) and that it more closely related to their career goals (Q4).

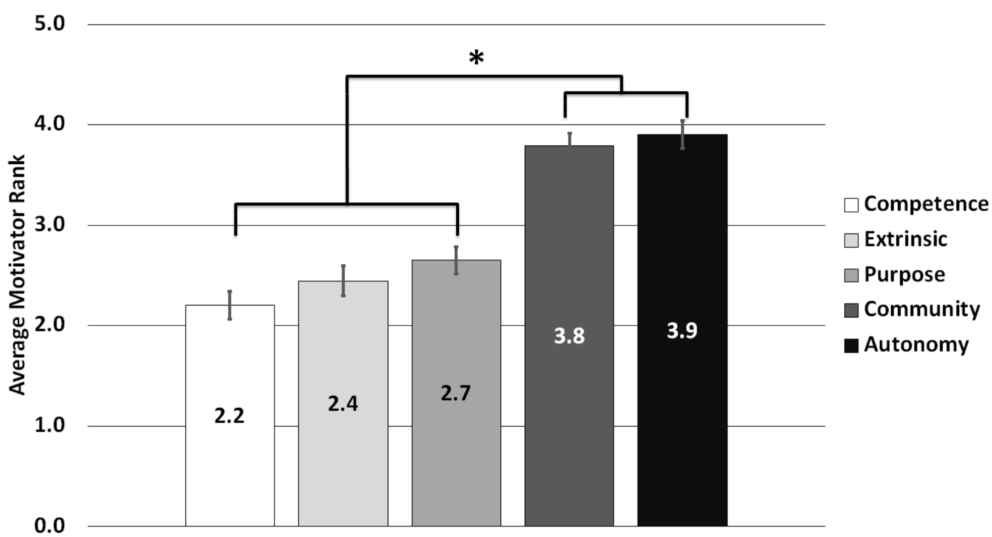


Figure 4: Comparison of student survey motivator rankings. Students ranked items related to competence, extrinsic motivation, and purpose significantly higher than

Discussion:

This study showed that a model eliciting activity implemented in an undergraduate-level biomechanics classroom resulted in greater amounts of intrinsic motivation for students versus standard homework assignments in the key areas of competence, autonomy, and purpose. Specifically, students found that the MEA was more frustrating than regular homework assignments (indicating different levels of competence), that they had greater choice in how to complete the assignment (indicating greater autonomy), and that the MEA related more closely to their career goals (indicating more of a sense of purpose). Interestingly, the teamwork inherent to completing MEAs did not result in reporting of a greater sense of community for the MEA compared to the standard homework assignment. It is possible that students working collaboratively to complete homework assignments resulted in the same feeling of “community” as working on a team to complete the MEA.

Increased frustration with the MEA may relate to student resistance to active learning. General comments on the survey indicated a greater desire for structure and guidance for the activity, which was antithetical to the purposes of an open-ended problem. Therefore, the expectations of active learning activities need to be better articulated for future iterations of this activity. Although problem-based learning activities such as MEAs have been shown to result in deeper learning of the associated content, they typically require more work and are more difficult and complex than problem sets assigned as homework. Ideally, by clearly communicating the reasons for this “tradeoff” between deeper learning and more complex assignments, student perceptions of the MEA as simply “more work” with no benefit over standard homework assignments can be minimized. Future work should investigate changes to student frustration with MEAs by assigning multiple MEAs over the course of the semester, and gaging how students adapt to repeating this cycle multiple times.

Self-reported ranking of student motivators indicated that, in addition to extrinsic motivations such as “getting a good grade,” intrinsic motivators of competence and purpose were equally as important to students. However, senses of autonomy and community were found to not be as important. The finding that competence and purpose are of the most personal significance to students is partially supported by previous educational research on self-determination theory, which posits that student learning is driven by psychological needs for competence and autonomy[1, 25, 26]. However, the finding that autonomy was among the least important motivators somewhat contradicts this. Even though autonomy was not consciously ranked as being most important, students did indicate having greater autonomy on the MEA assignment in terms of more choice in how to complete it. It is also possible that the phrasing of the item representing “autonomy” in the survey was not associated with autonomy by students. Regardless, a more robust survey of student motivation may further improve understanding of the importance of intrinsic motivation to students with regard to MEAs.

The moderate-strength correlations found in this study can indicate important considerations for the design of MEAs to support student intrinsic motivation. Mainly, students enjoyed the hip implant MEA more when they felt they were effectively learning the associated content, and saw a direct connection between practicing problem solving and applying concepts to the “real world” application of designing a hip implant. Lastly, students that felt they understood the expectations for the project also felt that the MEA helped them learn the content better. This further supports the importance of clearly communicating expectations of the MEA beforehand, and to ensure a clear connection between the learning objectives for the activity and the associated content to be learned.

Although various significant correlations were observed between survey questions, no correlations were observed between student grades on the assignment and survey responses. It is possible the distribution of scores on the project was insufficient to find correlations between grades and survey response questions. Additionally, no comparisons were made between survey responses and grades on homework or exam questions that covered similar content as the MEA. Therefore, it was not possible to evaluate the effectiveness of the MEA in learning the associated content, though this was not an explicit goal of the study. It must also be noted that student motivation was compared between a single MEA and student experiences with various homework problem sets of varying difficulty and complexity. The results of this study thus reflect general student motivation for this MEA compared to their overall experiences with homework assignments (i.e. problem sets) for the course. Future work should feature a more comprehensive questionnaire to evaluate student motivation at a greater number of levels and for specific assignments (MEA vs problem set) covering the same content. Furthermore, it should incorporate exam and homework scores across multiple class sections to better understand the effectiveness of the MEA for learning and retaining content in relation to the MEA’s level of improving student motivation.

Overall, this study found that a biomechanics-focused model eliciting activity enhanced student motivation compared to standard homework problem sets, especially in terms of student competence, autonomy, and purpose. Implementation of this MEA in the future will require clearer expression of the expectations for active learning activities to ensure the content is most effectively learned and applied. This MEA can potentially be improved by better targeting other intrinsic forms of motivation, such as autonomy and community, to more broadly stimulate student motivation.

Appendix A:

MEA Title: Hip Implant MEA

MEA Brief Description:

Student teams work for a research and design division of an orthopaedic medical device company that wants to expand their line of implants for hip replacement surgery. The company has requested the teams to produce a model that can be used by the design team to input dimensions and material specifications for proposed implant designs prior to developing a prototype. This model will be used by the design team to optimize the new implant design to use the least amount of material for a small form-factor implant that will still function properly, such that it meets all ASTM and clinical standards.

MEA Implementation Strategy:

- Pre-Reading Activity – Background readings on hip replacement surgery prosthetics and failure modes
- Individual Activity – Identify company clients who need the modeling tool
- Team Activity – Develop the model as defined in the "Model-Construction Principle" below.

Principle	Description	How the principle is addressed in the MEA?
Model-Construction	Ensures the activity requires the construction of an explicit description, explanation, or procedure for a mathematically significant situation ***Describe the mathematical model the students will be developing when solving this MEA:*** • ***What are the elements?*** • ***What are the relationships among elements?*** • ***What are the operations that describe how the elements interact?***	The student teams will produce a model (or procedure) that inputs body weight, implant neck diameter and length, implant stem diameter and length, and material properties (elastic modulus, shear modulus, yield strength, etc). It will output the stresses and deformations experienced by the model to compare to the maximum allowable by the implant before failure, defined from values in the scientific literature.

Reality	Requires the activity to be posed in a realistic engineering context and be designed so that the students can interpret the activity meaningfully from their different levels of mathematical ability and general knowledge ***Describe the context. What is the story?*** ***What knowledge will students need to bring to this problem?*** ***What background information must be provided?*** ***Describe how the problem is open-ended.***	The students work for a research & development unit of an orthopaedic medical device company that wants this model for developing new implants for hip arthroplasty. Although many mechanical, functional, and biocompatible issues must be considered when designing any prosthetic implant, the mechanical stability of the implant is a significant factor. The company wants to maximize the strength and functional capacity of a new implant while minimizing the amount of material required to create the implant, to both save money in production and provide surgeons and patients with a more compact option for hip arthroplasty surgery to differentiate themselves from the rest of the market.
Self-Assessment	Ensures that the activity contains criteria the students can identify and use to test and revise their current ways of thinking ***What is provided in this MEA that students can use to test their ways of thinking?***	The teams will be provided data about hip implants that already exist. They will use this information along with their prior knowledge about deformation, torsion, and beam bending develop a model. Teams can use what they know about solid mechanics to assess that their model conforms to their understanding about how a hip implant functions in a living patient. Literature data from mechanical testing of existing hip implants will be used to validate model performance.
Model-Documentation	Ensures that the students are required to create some form of documentation that will reveal explicitly how they are thinking about the problem situation ***What documentation are the students being asked to produce in this MEA?***	Teams will produce a memo to the client detailing the procedure to estimate the optimal dimensions of the new hip implant design. They will also provide an Excel spreadsheet to make the model more usable for the client.

Construct Share-Ability and **Re-Usability**	Requires students produce solutions that are shareable with others and modifiable for other engineering situations ***What will indicate to the students that a sharable, reusable, or generalizable solution is desired?***	*Share-Ability:* The teams must create the model for the company to use for current and future purposes. *Re-Usability:* The client can modify this this model for future use in designing other orthopaedic implants and prosthetics for other joints.
Effective Prototype	Ensures that the solution generated must provide a useful prototype, a metaphor, for interpreting other situations ***What are other examples of structurally or conceptually similar problems that would required a similar solution?***	Basic concepts of solid mechanics, specifically deformation, torsion, and beam bending, are introduced in this problem. Here students will apply theoretical principles of solid mechanics to practical design of an orthopaedic implant. Companies must ensure that their designs fit certain standards of function and safety (e.g. ISO, ASTM, FDA) to put their products on the market.

Appendix B:

Hip Implant Design Activity Pre-Reading

Learning objectives:

After completing this activity, students will be able to…

- Use solid mechanics equations to calculate strain and deformations resulting from beam bending and torsion
- Identify appropriate situations in which beam bending, torsion, and strain mechanics equations can be applied
- Design and evaluate a simplified hip implant that can withstand in vivo forces
- Write a brief report that communicates the findings of the hip implant model
- Sketch free body diagrams that illustrate the forces and moments acting on a solid body
- Explain the applicability of solid mechanics (specifically deformation/torsion/beam bending) to clinical situations.

Individually read the following information:

Since the first modern hip implant procedure was performed in 1960, hip replacement surgery (also known as total hip arthroplasty) has become one of the most commonly performed and successful orthopaedic procedures, with approximately 300,000 hip replacements performed annually. The hip is a ball-and-socket type joint between the pelvis and the femur. The head of the femur serves as the "ball" component, whereas the acetabulum of the pelvis serves as the "socket" with which the femur articulates. In the case of severe damage or wear to the cartilage in the hip joint, such as due to osteoarthritis, the components of the joint may need to be replaced with a hip implant. These implants consist of an acetabular cup component that is affixed to the pelvis, and a femoral component that articulates with the acetabular cup.

The femoral implant typically consists of a "stem" component that is inserted into the remaining femoral bone, and a "cup" component that the stem articulates with. The stem includes a "head" that articulates with the acetabular cup, and a "neck" that connects the head to the stem. The femoral implant is fixed to the femur by cement or is "press-fit," wherein the implant has a rough surface that allows bone to grow into and integrate with the implant for fixation. There is a large variety of implant designs that use different materials and dimensions to fit different applications of hip replacement. However, all implants must meet strict regulatory guidelines to be sold on the market, including Food and Drug Administration (FDA) safety regulations and ASTM testing standards (ASTM standard F2068). The femoral stem in particular must resist a wide variety of loading conditions resulting from combinations of normal body weight and gait forces in order to prevent significant deformations that can affect implant performance.

Individually, answer the following questions:

1. What primary considerations must be taken into account when developing a hip implant?

2. What are the main forces a hip implant would experience in the body? Draw a free body diagram to illustrate.

3. What are potential failure mechanisms for the femoral component of a hip implant?

Hip Implant Design Activity - Part 1

INTEROFFICE MEMORANDUM

TO: ENGINEERING DESIGN TEAM

FROM: JOHN SMITH, DIRECTOR OF RESEARCH DIVISION
GENERICO ORTHOPAEDICS, INC.

DATE: 3/28/16
RE: FEMORAL IMPLANT DESIGN UPDATES

Recently, our company has begun research and development on a new model of femoral stem for our line of hip implants for total hip arthroplasty. One of the goals of the new design is to minimize the dimensions of the neck and stem of the femoral implant. Not only will this save money on the amount of material required to manufacture the implant, but the smaller form factor will provide surgeons with a surgical option that allows for a greater amount of femoral bone stock to remain when fixing the femoral implant to the femur. As you are no doubt aware from previous memos, the FDA recently recalled a large number of hip prostheses from our competitors due to implant failure. It was suspected that their small form factor implants did not have sufficient strength or cross-sectional area to resist the required forces and moments applied to the implants during gait. Needless to say, we want to ensure that that our new designs will not suffer from the same problem.

Your team will be responsible for developing a tool our design teams can use to select the optimum dimensions for our new implant design. Ideally, the design teams should be able to input any variety of implant neck and stem dimensions, loading conditions, and failure conditions to determine if the potential design would be feasible before creating a prototype. The output of the tool should also be clear such that there is no confusion over interpretation of your model.

In order to begin work, the R&D team first needs you to provide them with information on what data is needed for you to develop your model. To assist them with the data collection process, please provide the following in a 1-2 page memo by **4/6/16**:

- The model equations you will use to optimize the design.
- The simplifying assumptions you will make about the model and the justifications for these assumptions.
- A list of the data and design parameters required to develop and assess the model.

Individually answer the questions below:

1) Who is the client (the direct user of the final product)?

2) In one or two sentences, what does the client need?

3) Describe at least two issues that need to be considered when developing a solution for the client.

Hip Implant Design Activity - Part 1

1. In your team, come to consensus about who the client is and what the client needs for the assigned task. Share your individual issues that need to be considered when developing a solution. Keep this information as a record to help you move forward. You do not need to turn this in.

2. In your team, reread the memo from John Smith and write a memo that includes:

    i. What models/equations will be needed to optimize the design?
    ii. What assumptions will you make about the behavior of your model and why?
    iii. What data would be needed to assess the model?

This memo, along with the individual questions, are due during recitation on 4/6/16.

Hip Implant Design Activity - Part 2

INTEROFFICE MEMORANDUM

TO: ENGINEERING DESIGN TEAM

FROM: JOHN SMITH, DIRECTOR OF RESEARCH DIVISION
GENERICO ORTHOPAEDICS, INC.

DATE: 4/5/16
RE: FEMORAL IMPLANT DESIGN UPDATES

Thank you for providing the R&D team with your models and assumptions for assessing the mechanical behavior of preliminary femoral implant designs. The team has collected data from our previous materials and models and done a literature review to provide you with the parameters you require to perform your analysis. Please see the attached tables of parameter values for details. Table 1 includes the variables needed to compute your outputs, while Table 2 includes critical failure parameters that the femoral implant must be able to withstand in order to evaluate proposed implant designs.

Your task now is to develop a spreadsheet using Microsoft Excel software to predict and evaluate the behavior of different femoral implant geometries. Users of the tool should be able to easily input different parameters and see the resulting calculations of stress and deformation. This tool will be used by the R&D team to narrow down their choice of designs before building and testing a prototype. Ultimately, you should provide recommendations to the design team for the following as a starting point for their designs:

- Minimum stem dimensions to resist excessive bending, torsion failure, and failure of the stem-bone interface
- Minimum neck dimensions to resist bending and fracture
- Appropriate material properties for the implant

The spreadsheet should include a free-body diagram of the full implant and individual diagrams for the neck and stem for easier interpretation of the results. The R&D team should also be able to easily compare any computed deformations and stresses to the critical failure values supplied in Table 2, such that any failed combination of design parameters can be rejected.

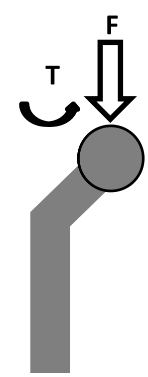
In addition to the spreadsheet, please include a memo to the design team with your recommendations for their designs. Ideally, this memo should include a clinical justification for your choices, which will be useful for explaining why our product is superior to other products on the market for surgeons to use. Please include any changes to your model or assumptions from your previous memo.

The R&D team needs these materials by **4/20/16** in order to begin their prototyping, so ensure all required materials are submitted by then.

Table 1 – Data for use in Excel Program to Predict Hip Implant Failure (units)	Symbol	Value
Elastic modulus (Co-Cr alloy) (GPa)[1]	E	110
Elastic modulus (Ti alloy) (GPa) [1]	E	230
Shear modulus (Co-Cr alloy) (GPa)[1]	G	90
Shear modulus (Ti alloy) (GPa) [1]	G	42
Max hip contact force on implant head (%BW)[2]	F	260
Max hip torsional moment on implant head (%BW m) [2]	T	2.24
Body Weight for "typical patient" (N) [2]	BW	920
Angle between stem and neck (°)	θ	130

Table 2 – Hip Implant Failure Data (units)	Symbol	Value
Compressive yield strength (Co-Cr alloy) (MPa) [3]	σ_y	450
Compressive yield strength (Ti alloy) (MPa) [3]	σ_y	758
Maximum allowable bending deformation (mm) [4]	v_c	10
Maximum allowable shear stress at implant-bone interface (MPa) [5]	τ_c	3
Maximum allowable twist at bone end of stem (°)	Θ_c	1

1. Cheal et al. J Orthop Res. 1992; 10:405-422.
2. Bergmann et al. J Biomech. 2001; 34:859-871.
3. Staiger et al. Biomaterials. 2006; 27:1728-1734.
4. Nganbe et al. J Biomed Mater Res B Appl Biomater. 2011; 97(1):132-8.
5. Ramaniraka et al. J Bone Joint Surg Br. 2000; 82-B:297-303



Hip Implant Design MEA Post-Activity Questions

Individually, answer the following questions:

1. What other factors must be considered for the function and design of a hip prosthesis other than the strength and stiffness of the material used to manufacture it?
2. If a material were much stiffer and stronger than the bone in which it is embedded, how might that effect the bone over a long period of time?
3. Why is it important for there to be a specific set of manufacturing standards (e.g. FDA, ASTM) for medical devices?
4. What types of materials can be used to make a hip prosthesis? What are benefits and drawbacks of each?
5. How do you think the simplifications/assumptions you made to represent your implant (e.g. geometry, loading, material behavior, etc) would result in different behavior from actual deformations that would occur in the body?

The final spreadsheet, memo, and post-activity questions are all due on 4/21/16.

Appendix C:

Hip Implant Design Project Rubric

Category	3	2	1	0
Pre-Activity Questions	Thoughtful and detailed responses to all questions	All questions adequately answered	Some questions answered	Not answered
Model Equations	All equations to fully describe the mechanical behavior of the implant are included	Most of the required equations are present to calculate all needed outputs	Significant equations to adequately describe model are missing	No equations provided
Assumptions	Detailed justifications for all required assumptions are provided, no missing assumptions	Adequate justification of assumptions provided, significant assumptions included	Insufficient justification for assumptions, significant assumptions missing	No justification of assumptions/no assumptions provided
Free-body Diagram (FBD)	FBD for full implant includes all loads acting on the component. Separate FBDs also included for stem and neck portions with correct application of loads.	FBD for full implant with all loads included, but separate FBDs for stem and neck missing	Partial FBD with forces and moments, but important loads are missing	No FBD
Spreadsheet Implementation	Spreadsheet properly implements all needed equations to calculate beam bending, torsion, deformation, and stress in stem and neck. All output values are compared to critical safety values to determine if implant would fail	Correct implementation of equations and calculations of all required outputs, but no comparison to critical failure parameters	Partial implementation of equations, important outputs missing	No spreadsheet
Spreadsheet Layout and Usability	Spreadsheet is cleanly organized such that the user can easily input all values and see the outputs of deformation and stress, then compare them to critical failure parameters.	Spreadsheet is generally cleanly laid out, but it is difficult to make easy comparisons	Spreadsheet is cluttered and difficult to read and use	No spreadsheet
Post-Activity Questions	Thoughtful and detailed responses to all questions	All questions adequately answered	Some questions answered	Not answered
Evaluation	Memo includes analysis of results that provides recommendation for implant dimensions with clinical justification	Discussion of results with recommendation, but no clinical justification	Partial discussion of results with no recommendation	No discussion of results

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