

Design PhD Qualifying Exam Information Sheet and Instructions



Objective

The objective of this exam is to evaluate and assess the skills, knowledge, and ability of a potential PhD candidate in design practices, processes, and applications. Successful students will be able to demonstrate understanding of the fundamental principles of design, communicate, describe, and assess designs through artifacts, and solve design problems applying appropriate tools and methods. This exam is meant to assess the PhD Program Outcomes of *subject mastery* and *independent learning*.

Exam Instructions

- For this exam, two of the three questions provided should be completed.
- Each question has equal weight.
- This exam is open book, open notes, with the exception that solution manuals are not allowed.
- Cell phones and other electronic devices are not permitted in the exam room.
- The exam has a time limit of 2.0 hours.
- Work each problem on a separate sheet of paper.
- Only turn in the problems to be graded.
- To allow anonymity during the grading process, each student will be given a pseudo-random identifier and will place their identifier (not their name) on all answer sheets.
- A score of 70% or higher is considered a passing grade.

Exam Topics and Learning Objectives

A successful exam candidate should be able to:

1. Evaluate the quality of design methods, activities, and outcomes
2. Evaluate the quality of design artifacts
3. Demonstrate fluency in developing concepts to solve design challenges

4. Demonstrate effective decision making skills and techniques for selection of alternatives throughout the design process
5. Select and apply an appropriate design tool for a required design artifact
6. Articulate an appropriate design process for a given design product or challenge
7. Translate customer statements to market requirements and/or performance measures
8. Develop basic engineering models for mechanical systems and product designs
9. Perform engineering design of fasteners, springs, and gear systems

Representative courses at BYU:

MeEn 475: Product Development 1- Capstone
MeEn 476: Product Development 2- Capstone
MeEn 482: Manufacturing Systems Analysis and Design
MeEn 472: Mechanical Systems Design Applications

Representative texts:

Mattson and Sorensen, *Fundamentals of Product Development*
Groover, *Fundamentals of Modern Manufacturing*
Norton, *Machine Design: An Integrated Approach*

SAMPLE PROBLEMS

NOTE: THESE PROBLEMS ARE REPRESENTATIVE OF THE TYPE OF PROBLEM THAT MAY BE ON THE EXAM. THIS IS **NOT** A SAMPLE EXAM.

Problem 1:

You have been asked to design a toy suitable for distribution by humanitarian organizations to people around the world suffering the effects of war or natural disaster. You are given the following broad criteria for the toys:

- Dimensions should not exceed 8" x 8" x 4"
- Moving parts need to be securely attached and work properly
- Toys should not be linked to American culture
- Avoid military, religious, violent, or scary toys

a) Need Statements.

i) Process for determining needs

Describe the process you would follow to determine customer needs. Be as specific as possible in your description of the process. Demonstrate that you understand good methods to determine the needs for this product.

ii) Needs hierarchy

Although you have not been able to completely follow the process in part i), you should still be able to determine some needs from your experience. Based on your experience and the broad criteria above, generate a needs hierarchy for the toy you are designing. The need statements should be as comprehensive as possible within the time available for the problem. Needs statements should be expressed in appropriate terms with relative importance of the different needs expressed.

iii) Process evaluation

Evaluate the quality of your needs hierarchy. Your work was extremely limited due to time, so it is expected that it is imperfect. What are the strengths and weaknesses of your needs hierarchy? List one or two improvements you would expect to result from following the process identified in part i).

b) Product Specifications.

i) Process for determining specifications

Describe the process you would follow to determine appropriate specifications for your needs. Be as specific as possible in your description of the process. Demonstrate that you understand good methods to develop specifications from a needs hierarchy.

ii) Creating productspecifications

For several of the needs identified in the needs hierarchy, create product specifications related to the need. Each specification should include a metric, a marginal value, and an ideal value. The specifications identified for each need should be comprehensive enough to ensure that the need will be met if the specifications are met.

iii) Process evaluation

Evaluate the quality of your specifications. What are the major strengths of your specification set? What are its major weaknesses? What is the most important thing you'd like to improve if you had the resources available to do so?

Problem 2:

You have been asked to design a toy suitable for distribution by humanitarian organizations to people around the world suffering the effects of war or natural disaster. You are given the following broad criteria for the toys:

- Dimensions should not exceed 8" x 8" x 4"
- Moving parts need to be securely attached and work properly
- Toys should not be linked to American culture.
- Avoid military, religious, violent, or scary toys

a) Concept Generation

i) Process for generating concepts

Describe the process you would follow to generate product concepts. Be as specific as possible in your description of the process for this particular toy. Demonstrate that with sufficient resources, you would be able to develop an excellent set of generated concepts. In describing your process, focus on this particular design, rather than a generic design problem.

ii) Initial concept set

Subject to the limitations of time and location for this exam, generate an initial concept set for the toys described in the problem statement. Your concept set should be demonstrated to be excellent, subject to the limitations of the exam.

iii) Process evaluation

Evaluate the quality of your initial concept set. Your work was extremely limited due to time, so it is expected that it is imperfect. What are the strengths and weaknesses of your concept set? What is the most important improvement you would like to make if you were to continue on this project?

b) Concept Selection

i) Preliminary concept selection

Based on a subset of your initial concept set, use the screening process to select a few concepts for further work. Describe the process you used to screen the concepts.

ii) Process evaluation

Evaluate the quality of your concept screening. Do you believe that you have identified excellent concepts for more work? Why or why not? How would you change things with more time to complete the screening process?

Problem 3:

You have been asked to design a new adult pogo stick for the weight-loss market. In contrast with existing designs, this pogo stick is aimed at overweight adults. A specification for the final product is that it is safe to use for an adult weighing 280 pounds. Design an appropriate spring for this application, given that the total spring travel needs to be at least 9 inches. The design should include information on both material and geometry for the spring. Be sure to consider the dynamics of the pogo stick in your design considerations. Show all work, and clearly state any assumptions made.

Note: the default type of spring for a pogo stick is a coil spring. However, you are free to choose some other type of spring, should you desire to do so.

Problem 4:

You have the opportunity to start a garage-based business creating hot-melt adhesive sheets for portable friction stir welding equipment. It is expected that purchasing the tooling for this product will cost approximately \$250,000. Development time for this product will be about six months, at \$25,000 per month. Net revenues from the product are anticipated to be \$2,000 per month for the first six months after the start of production, \$8,000 per month for the next six months, and \$10,000 per month for the next five years.

Does this project make financial sense, i.e. would you be willing to start this business? Justify your answer on the basis of financial calculations, including the time value of money.

Problem 5:

Compare and contrast modular product architecture vs. integral product architecture. Discuss the advantages and disadvantages of modular product architecture. Describe the

conditions that lead to an integrated architecture, and those that lead to modular architecture. Give examples of successful products with both types of architecture.

Problem 6:

You have been asked to design a residential keyless locking system suitable for single family homes in Provo and similar cities (i.e., keyless entry into home).

- a) Three stakeholders were interviewed regarding the prospect of a residential keyless locking system. Given their response (boxed below), describe the process you would follow to determine appropriate specifications from these statements. Be as specific as possible in your description of the process. Demonstrate that you understand good methods to develop specifications from stakeholder/customer statements.
- b) Based on the stakeholder statements (boxed below), develop a set of specifications that would ensure the stakeholder statements are satisfied. Provide metrics, marginal values, and ideal values.
- c) Evaluate the quality of your specifications relative to the stakeholder statements. Provide an insightful discussion that considers these questions: What are the major strengths of your specification set? What are its major weaknesses? What is the most important thing you'd like to improve if you had the resources available to do so?

Stakeholder Statements

From interview with installer:

1. I don't want to have to connect the locking system to any electrical circuit in the house.
2. Utah has a large swing in annual temperatures; I hope the new device can handle it.
3. The new device needs to be really easy to install because they're already going to be spending a lot of money on the lock itself.

From interview with potential user #1:

4. I don't want it to look strange or bulky on my old house, it really should look like the other locks.
5. I don't want to get locked out of my house if the new lock malfunctions.

From interview with potential user #2:

6. The keyless feature is only interesting when I am outside and going in. I would like the lock to be more conventional when I am inside and going out.
 7. If I buy this product, I want it to be noticed by my neighbors, even to the point of being the center of lively discussions.
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Problem 7:

Imagine that Apple has just announced the iPhone 4, which greatly adds to the capabilities of the iPhone 3GS. You have come up with a great idea to integrate the iPhone with the Wii to give an improved gaming experience.

Because the iPhone 4 is such an advance on the iPhone 3G, an entirely new App Store is opening. (The App Store is where all software for the iPhone will be sold, typically at a cost of \$9.99 or less). The new iPhone and App Store are scheduled to go online in three months.

After getting the software development kit, you determine that it will take you about 9 months to get your application ready for release, working nights and weekends. However, you also have the option to hire an experienced developer to develop your application; she would be able to complete the job in three months at a cost of \$25,000.

Including the time value of money, and making assumptions about costs and revenues, build a financial case that will help make the decision whether or not to hire the developer. As is the case in nearly all decisions made early on in the product development cycle, information is scarce and uncertain, so you should include the effects of uncertainty in this analysis.

Problem 8:

You have been asked to design a device to launch snowballs (of 3 inch diameter). You are given the following broad criteria for the device:

- Dimensions should not exceed 24" x 24" x 24"
 - Device should not require electricity to operate
 - Device should be easily operated by able-bodied individuals age 11 and up
 - Device itself should be safe to operate
- a) Provide a brief*, but insightful, description of the design process steps that lead to the important activity of *Concept Generation*. Tailor this description to a new designer working on your snowball launcher design team.
- b) Subject to the limitations of time and location for this exam, generate and quickly sketch an initial concept set for the device described in the problem statement. Describe the process used to generate these concepts. The description of the process should demonstrate your knowledge of good concept generation processes.
- c) Evaluate the quality of your initial concept set. Provide insightful discussions

that answer the following questions: What are the strengths and weaknesses of your concept set? What is the most important improvement you would like to make if you were to continue on this project?

*probably not more than 8 minutes.

Problem 9:

You are designing a product that interfaces with another company's product where the output shaft of the other product is the input for your product. The input to your system is a shaft that produces 10 in-lb of torque at 1800 rpm (revolutions per minute). Your system needs to convert this to an output rotation of approximately 50 rpm.

- a) Considering only the limited information above, what are some of the design options (e.g. spur gear train) for creating this device?
- b) Design a two-stage compound gear train that accomplishes this objective. Sketch the gear train and state the resulting gear diameters and number of teeth for each gear. State any assumptions made.
- c) With the given input torque and gear ratio, what is the maximum output torque you could expect at the output shaft? What contributes to making the output torque less than this theoretical maximum?

Problem 10:

You work for a manufacturing company. One of your manufacturing stations requires an operator to stand for long periods of time doing simple repetitive tasks on a horizontal workspace. Few operators find the workspace height optimal for low fatigue. In response, you design a workspace that can be easily adjusted in height between 30" and 42" by different operators.

- a) Quickly generate and sketch several diverse (and reasonable) concepts for raising and lowering the workspace. Demonstrate creativity and make sketches clear enough to be understood by the person evaluating your test.
- b) Thoughtfully construct a weighted decision matrix to rank your generated concepts. Be sure to choose reasonable criteria, weights, and concept ratings.
- c) Insightfully describe common challenges, and any solutions, associated with the concept generation and evaluation methods you used.

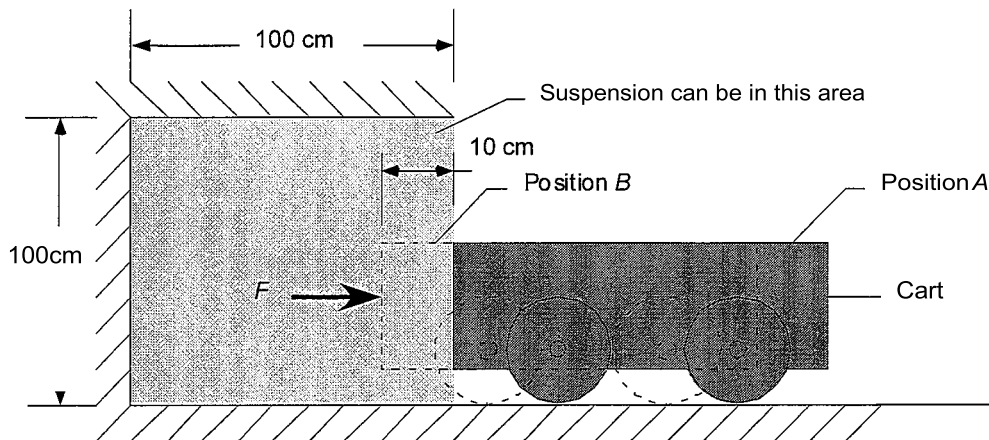
Problem 11:

You are the chief design engineer for a start-up company that wants to enter the sunglasses market. Your company will design and sell the sunglasses, and chooses to not outsource any design/engineering activities.

- a) Sketch and describe a customized development plan that can be used for this specific product.
- b) List specific design activities for this specific product that you recommend be used in each part of the plan.
- c) Choose one part of the plan where you feel the largest amount of design ambiguity exists. Describe how you would deal with this ambiguity.

Problem 12.

You are designing a test equipment cart that requires a suspension to absorb lateral loads. The equipment cart rolls on wheels as shown below. The suspension element should fit within the shaded area to the left of the cart. The suspension element should offer no resistance when the cart is in position A, and should resist with a force of $F = 1,000\text{ N}$ when moved 10 cm to the left (position B).



- d) Describe several different design options (e.g. helical coil spring) for the suspension.
- e) Discuss the tradeoffs of the options mentioned above.
- f) Select one of the methods and provide more information on the suspension design (e.g. dimensions and material properties of a helical coil spring). Describe the design tradeoffs in your design.

Problem 13.

Assume you are working on the development of a new residential door lock that will use fingerprint recognition technology to avoid the need for keys.

You had a planned 18-month development schedule, culminating in a product release scheduled in six months from now. You have spent \$1.5 million over the past year; your plan calls for spending \$900,000 in development costs over the next six months.

Your marketing team has prepared a plan that indicates a three-year lifespan from the first date of sale for this product, with sales of 30,000 units the first year, 60,000 units the second year, and 120,000 units the third year. It is expected that you will release the next generation of automatic locks in the middle of the second year; generation 2 is expected to have sales of 20,000 units that year and 150,000 units the following year.

Production costs are expected to be \$60.00 per unit for the first year, dropping to \$50.00 for years 2 and 3. The wholesale price for the product is expected to be \$80.00.

Due to the use of a contract manufacturer, the ramp-up costs are expected to be negligible. Marketing and support costs are expected to be \$1.5 million per year.

- a) The company has only \$150,000 remaining. You have the possibility of borrowing \$750,000 to complete the development at an interest rate of 12.5%. Does it make sense to borrow the money to get the product to market? Justify your answer with appropriate financial calculations.
- b) One of the engineers working on the project suggested that it might be nice to add retina scanning ability to fingerprint recognition. It is anticipated that this would add 6 months and \$1 million to the development costs. Marketing suggests that this might increase the market volume by about 10%. Assuming you would need to borrow the extra money, again at a rate of 12.5%, would you recommend that the retina scanner be added? Justify your answer with appropriate financial calculations.
- c) Your contract manufacturer has an in-house development team that is skilled in developing products like yours. They've offered to complete the development in 3 months instead of six months, at a cost of \$1 million. Describe financial and non-financial arguments for outsourcing the remaining development as well as for keeping the development in-house. Including the financial effects, recommend whether the development should be outsourced.