# A Straightforward Method of Project Definition for Capstone Design Projects

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A common issue with open-ended capstone design projects is their initial definition. That is, collecting customer requirements and turning them into verifiable engineering specifications. There are many common difficulties with this extremely important early step in the design process. Oftentimes sponsoring organizations are unclear in communicating the requirements, or even unaware of what they should be. Senior students are typically not experienced in the process, and often lack a detailed understanding what's involved in generating a complete set of engineering specifications.

The capstone design program at California State University Chico has developed a straightforward method of project definition that is easy to understand and apply. It is particularly useful for project sponsors that may not have completely thought through want they want the designs to do. It is also an excellent tool for guiding inexperienced students through the process for the first time.

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## Overview of Capstone Design

The mechanical and mechatronic engineering programs at California State University Chico utilize a two-semester capstone course in senior design project. The intent is for students to utilize competencies developed in the first three years of the curriculum in the solution of a real-world design problem. Projects are primarily sponsored by industrial partners, which is consistent with many capstone engineering courses nationwide[1].

During the first semester, weekly lectures are given that cover many aspects of the design process. Selected topics include project definition, conceptual design, decision making, project management, cost estimating, budgets, teamwork, simulation, documentation, and formal reports. Each project group is required to give three oral presentations during the semester, which concludes with submission of a comprehensive design report.

The second semester includes less time in the classroom and more time spent building and testing the designs. Students develop a comprehensive test plan to prove the engineering specifications developed early in the first semester. The second semester continues with fabrication and testing, then concludes with a final oral presentation, display of prototype hardware (including a project poster), and submission of a comprehensive written report.

The design projects are accomplished by student groups[2], as the ability to work in groups is one of the measured outcomes of the course. Groups typically number four to five, but may vary based on the complexity of the assigned project. Groups are typically multidisciplinary with students from both mechanical and mechatronic engineering, with the mix dictated by the technical aspects of the particular project. Regardless, each group is assigned a single faculty advisor for the duration of the project, considered by many to be a critical element[3] of the student's design experience.

## Overview of the Design Process

There are numerous, varied definitions of the design process, but most begin with identifying a need and conclude with verification that the design was (or was not) successful. For the purposes here, the design process is summarized in the following enumerated steps, with the acknowledgement that portions of the design process are often iterative:

1. Identify the Need
2. Define the Problem
3. Plan the Project
4. Gather Information
5. Develop Concepts
6. Evaluate Alternatives
7. Select Best Alternative
8. Detailed Design
9. Document the Design
10. Implement the Design

The focus of this paper is on the second step of the design process, defining the problem. Before discussing project definition in detail, it is important to clarify what is meant by the first step, identifying the need. In a general context, need may be market driven, or may be a new product without market demand. It may also be an internal project or process not related to an external product.

In the context of an educational capstone design project, the need presumably has already been identified. That is, the sponsoring organization has brought forth a design project for a team to work on. This implies that the need is fully identified, but it is important to recognize that this is often not the case. It is very common for the design team to have to "extract" from the sponsor exactly what they want the design to do. In essence, they are determining why the sponsoring organization is willing to allocate funding and resources to the problem. In those cases, steps one and two are actually being accomplished concurrently.

## Overview of Project Definition

As considered here, project definition begins with customer requirements and concludes with a set of verifiable engineering specifications. It is arguably the most important step in the design process, with more design project failures attributable to this phase than any other.[4]

Successful project definition is evidence that the design project is understood, well defined, and justified. The results of project definition guide the remainder of the design project, and are crucial to being able to eventually answer the question: *How will you know if your project is successful?* It is simply not possible to progress effectively with the remaining steps of the design process without a fully defined problem.

Much has been written on the subject of project definition and its variants which include problem definition, problem formulation, project justification, etc. There are many techniques and procedures discussed and presented in the literature, each with their own strengths and weaknesses.

While an exhaustive listing, summary, and dissection of popular methods is not possible within the scope of this paper, several of the more common techniques are listed in Table 1.

Table 1 – Popular Problem Definition Techniques

| Technique | Ref |
|---|---|
| Criteria Trees | 4 |
| Functional Analysis | 4 |
| Quality Function Deployment | 5 |
| House of Quality | 6 |
| Functional Decomposition | 7 |
| Product Usage Context | 8 |
| Human Centered Design | 9 |

Some of these techniques have been utilized directly in our program (with varying degrees of success), while elements of many others have been considered and implemented in part or in whole. The primary reason that so many different approaches have been attempted is that no single method has provided fully satisfactory results.

Many techniques proved difficult to communicate to students, where confusion reigned over the meaning of nebulous and overlapping terms such as customer requirements, needs, engineering requirements, criteria, objectives, constraints, goals, attributes, characteristics, functions, and targets. Difficulties were also encountered with project sponsors, who either didn't understand the necessity of project definition, or didn't want to "tie the hands" of the student teams and overly constrain the design process. There were also issues with faculty advisors not completely understanding the methods or being consistent in their terminology, further confusing students and sponsors.

## Project Definition Simplified

A simplified, streamlined, procedure to accomplish project definition in the context of capstone design projects has been developed. Though it shares aspects with previously mentioned methods, the specific procedure and terminology in particular are unique. The procedure has not only proven to be successful at generating a good set of engineering specifications, but also has excellent utility in teaching the process to students and sponsors alike. The procedure is broken down into the following six steps which are explained in detail below:

1. Identify the customer(s)
2. Determine customer requirements
3. Prioritize requirements into categories
    - Must Do / Should Do / Would be Nice
4. Classify each customer requirement as Quantitative or Qualitative
5. Establish specifications and metrics for each quantitative requirement
6. Set target values, tolerances, and any special conditions for each engineering specification

## Identify the customer(s)

The project sponsor is often thought of as the exclusive customer, but that often is not the case. Customers may also include the end user of the product or others with a stake such as manufacturing, marketing, retailer, or a service entity. It is important for students to understand this distinction, and have a clear understanding of who their customer(s) is (are).

## Determine Customer Requirements

Customer requirements can be thought of as wants and needs that are generally expressed in the customer's words. Ideally these are stated in the positive sense rather than the negative of the existing situation. For example, a sponsor may use terms such as lightweight, inexpensive, easy to assemble, and reliable to describe aspects of the intended design. Some sponsors, particularly those who have worked with the program before, have already given this substantial thought and clearly articulate requirements to the students. But others may not have decided themselves what they want the design to do. In those cases, students are instructed to meet with their sponsors, and if necessary, "extract" the customer requirements by asking appropriate questions about the design until all of the customer's wants and needs have been uncovered.

### Prioritize Requirements into Categories

While the terminology used in this section is somewhat colloquial, we have found it to be extremely effective in sorting out the most important aspects of the design. For each customer requirement identified in the previous step, students assign one of three relative importances: *Must Do, Should Do, or Would be Nice*. If a requirement is placed in the first category, it simply means that any considered design solution must meet that requirement. If a concept is put forth that will not meet it, it's discarded. *Should Do* requirements are those that the design should meet, but there may be some leeway if promising alternatives emerge that are superior in other areas. Requirements classified as *Would be Nice* are generally non-essential features or capabilities that might be included in the design if time and resources allow, but should not be a driving force in the decision process.

It's worth noting that *Would be Nice* was developed out of a listening technique from hundreds of customer information-gathering sessions. The customer seems to naturally just say those words or variations, and an engineer taught to listen for them is often able to record the requirement with proper perspective assumed, or more importantly, not record them as a higher priority item.

### Classify each Customer Requirement as Quantitative or Qualitative

By simple definition, quantitative requirements are numerically based while qualitative requirements are described by characteristics. But the definitions need to be changed in this case to consider how the requirement will be met. We define quantitative requirements as those that will require a procedure to measure. All others are qualitative. A favorite example put forth to the class is a project to design an efficient one-person hybrid vehicle. The project has a customer requirement that the vehicle have three wheels. If asked, the class will inevitably say that the requirement is quantitative, since it is numerical in nature. In fact, the requirement is qualitative, since it can be verified by simple observation. Another example would be a nebulous requirement such as requiring the design to be aesthetically pleasing. In the same way, most students will identify this as qualitative, which it would be if the sponsor planned to simply assess it by observation. But that same requirement would be quantitative it were to be measured by analyzing survey data from focus groups formed to assess the aesthetics of a particular design alternative. If it's unclear which category a requirement belongs to, it should be considered quantitative going forward to the next step, which when complete should fully establish its category.

### Establish Specifications and Metrics for each Quantitative Requirement

As stated earlier, quantitative requirements are those that will require a procedure to verify. For each one, students must determine a measureable engineering specification along with a measurement metric and method and/or device. In simpler terms, this is presented as "*What are you going to measure?*" and "*How are you going to measure it?*" It is well known that quantitative requirements must be measureable, but forcing students to think through the process of exactly what will be measured, and how it will be measured, early in the design process, generally results in a more realistic engineering specification.

### Set Target Values, Tolerances, and any Special Conditions for each Engineering Specification

Target values and tolerances must be established for each engineering specification. These can be thought of as the measurements you hope to achieve during testing of the design. Targets are often specified directly by the sponsor. For example, the weight capacity of a lift or the cycle time of a robot arm. An important aspect of target values that is often overlooked are any special conditions under which the measurement will take place. For example, if a specification for a robot arm is a cycle time of less than 5 seconds, the conditions of the test (distance traveled, mass of payload, etc.) must be clearly defined. In simpler terms, for each measurement, students must define "*Under what conditions*" and "*To what target value*" the measurements will be made. The six step process of project definition is depicted graphically in Figure 1.

### The Utility of Project Definition

As stated earlier, successful project definition is crucial to successful completion of the project. Several subsequent stages of the design process are completely reliant on project definition. During conceptual design, many alternatives can be eliminated early on by simply referring to the *Must Do* requirements. That is, if a

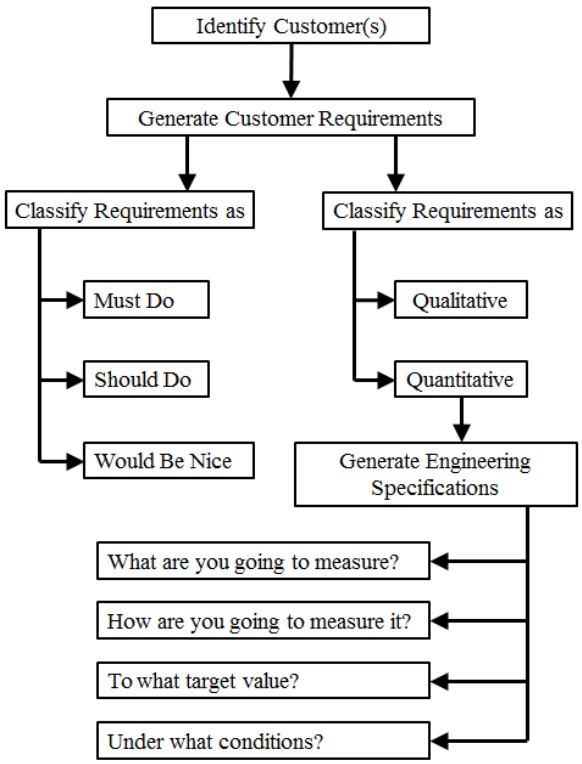


Figure 1 – Project Definition Flow Chart

proposed design concept will not meet a *Must Do* requirement, it's eliminated from consideration without further investigation.

A common tool for narrowing concepts is the decision matrix, also known as a Pugh's Method[7]. Two important steps in a Pugh analysis include generating criteria that will be used to compare alternatives, then ranking, or weighting them based on their relative importance. Both of these steps can come directly from project definition, with the criteria coming from the list of customer requirements and the weighting factors dictated by their relative importance (*Must Do*, *Should Do*, or *Would Be Nice*).

A further utility of the method occurs during design reviews with the sponsor. As a design progresses, sponsors may feel the design is not headed in the right direction, or may call into question decisions made by the design team. Continual referral to project definition helps keep the students on track and also reminds the sponsor of the original intent of the design. It is also a valuable tool when discussing proposed design changes.

Virtually all aspects of detailed design are also driven by problem definition. Nearly every calculation used for component selection is based on engineering specifications and meeting target values. It simply is not possible to make the hundreds of decisions required in the detailed design phase of a project without first fully defining it.

A final yet critical phase of any design project is testing. That is, answering the question, *was the project successful?* This is often the first time students are tasked with writing detailed test procedures. This difficult assignment is made substantially easier by having already determined which requirements must be verified by detailed procedure and which ones can be verified by simple inspection, and by answering the following four questions: *What are you going to measure? How are you going to measure it? To what target value? Under what conditions?*

## Conclusion

Project definition is arguably the most important step in the design process. It is difficult to communicate its importance and execution to students and often to project sponsors as well. The straightforward prescriptive method presented here has proven to be a successful tool for project definition. It results in a thorough understanding of the project by both students and sponsors, and facilitates the writing of a complete set of engineering specifications, which is considered by some to be proof that the design team understands the problem[7].

## References


1. Todd, R. H., Magleby, S. P., Sorensen, C. D., Swan, B. R., Anthony, D. K., "A Survey of Capstone Engineering Courses," Journal of Engineering Education, April 1995
2. Watkins, G. K., "Group Selection Techniques for a Mechanical Engineering Senior Design Project Course," proceedings of the 2008 American Society of Engineering Education Annual Conference
3. Somerton, C. W., Thompson, B. S., Gunn, C., "The Role of the Faculty Advisor in the Capstone Design Experience: Importance of Technical Expertise," Proceedings of the 2003 American Society for Engineering Education Annual Conference
4. Hyman, B. (2003) "Fundamentals of Engineering Design," Prentice Hall, Pearson Education, Inc.
5. El-Haik, B. and Roy, D. M. (2005) "Quality Function Deployment (QFD), in Service Design for Six Sigma," John Wiley & Sons, Inc.
6. Hauser, J. R. and Clausing, D., "The House of Quality," Harvard Business Review, 1988
7. Ullman, D. G., (2003) "The Mechanical Design Process," McGraw-Hill
8. Green, M.G., Palani, R.P.K., and Wood, K.L. "Product Usage Context: Improving Customer Needs Gathering and Design Target Setting," 2004 ASME Design Engineering Technical Conference
9. Brown, T., (2009) "Change by Design," Harper Collins Publishers