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# Evaluation of Ecosystem for Design Assessment and Verification by BAJA Dynamometer Capstone Team at the University of Nebraska

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## Abstract

This paper summarizes the outcome of an evaluation by capstone design teams from the Department of Mechanical and Materials Engineering at the University of Nebraska-Lincoln, of the Ecosystem for Design Assessment and Verification. The Ecosystem is a design decision support tool whose main goal is to identify design oversights, defined in terms of deviations from the design process or unfulfilled design requirements, early in the design process, guide designers through the design process, and teach proper design techniques. It is capable of automatically assessing students' design work against ABET compliant learning outcomes. The Ecosystem offers many additional features found useful by capstone design teams, such as automatic generation of formatted project reports as well as interfaces to tools for team communications (Google Drive, Dropbox or OneDrive) or development (e.g., SolidWorks, CATIA, NX Unigraphics or AutoCAD).

The Ecosystem was recently evaluated by a capstone team working on an automated straw flattening machine and again during a following semester by a team designing a dynamometer used for measuring the engine power of a BAJA race car.

The paper draws upon the improvements of the Ecosystem software completed during the aforementioned time period, identifies the features the capstone teams found most useful, and compares the design experience (productivity) of the BAJA Dynamometer team to that of the a team not using the Ecosystem, but with the same faculty adviser. Through comparison of two such teams, it was found that the team using the Ecosystem managed to stay on schedule a little better.

## Keywords

Design process, design assessment, requirement verification, productivity improvements

## Introduction

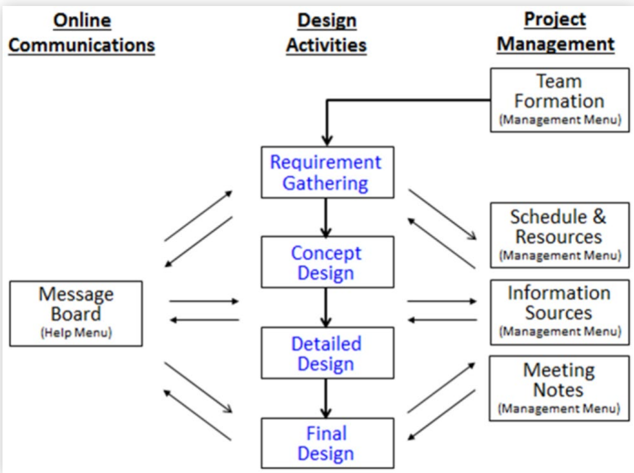
The capstone program at the University of Nebraska-Lincoln consists of two classes: Mechanical Engineering Design I (MECH 446) and Mechanical Engineering Design II (MECH 447). MECH 446 is a "theoretical" class on engineering design, while MECH 447 is the "practical" class. Both classes run concurrently on a semester calendar, but students typically take the classes in successive semesters.

This paper expands on [1] and illustrates complete (start-to-finish) application of the Ecosystem on a representative capstone project involving mechanical design.

## Ecosystem for Team Design and Assessment

The Ecosystem is a generic design framework aimed at early identification of design oversights. It is an electronic journal of the complete design history. While the Ecosystem formulates a fairly traditional waterfall design process by default, with the typical design steps presented in Figure 1, it is quite flexible, both in terms of structure of the design steps and the design terminology [1].

**FIGURE 1** Typical design flow through the Ecosystem.






The Ecosystem can guide designers through the design process, in a structured fashion, support the learning of proper design techniques, and help eliminate productivity interruptions. To this effect, Ecosystem provides friendly, real-time advisories. The Ecosystem supports learning outcomes derived from generic learning objectives for engineering design issued by the Accreditation Board for Engineering and Technology (ABET) [1].

The Ecosystem offers automatic & objective assessment (scoring) of

the design activities relative to the design process. The students and instructor can avoid spending time on elementary oversights, and instead focus on higher-level learning and problem solving. It also provides multiple features aimed at facilitating communications within design teams or with external stakeholders. It offers seamless access to design files stored on Google Drive, OneDrive or Dropbox, and automatic generation of formatted project reports [1, 2, 3].

Table 1 summarizes the Ecosystem's primary benefits to designers, supervisors and sponsors [1].

# Dynamometer for Centrifugal Clutch Tuning

## Project Objectives

The BAJA SAE team at the University of Nebraska-Lincoln frequently removes the engine and Continuously Variable Transmission (CVT) from their vehicle in order to tune and improve the vehicle's performance on a race track. Removing and reinstalling these components takes an extensive amount of time and effort for the BAJA team. For this reason, the goal of this project was to research, design and fabricate an engine dynamometer that would allow the team to tune and test their engine and CVT configuration *before* installing into the vehicle [4, 5].

**TABLE 1** The Ecosystem's primary benefits to designers, supervisors and sponsors.

| Designers (Students) | Supervisors (Instructors) | Sponsors |
|---|---|---|
| • Learning of proper design techniques.<br>• *Improved productivity*, planning and team work.<br>• Greatly helps in terms of general organization and oversight avoidance.<br>• Automation of many administrative tasks.<br>• Editable progress reports (no duplicate entry) | • Guarantees all students go through same design process.<br>• Having software teach key concepts and methodology, and identify elementary oversights, frees up instructor bandwidth.<br>• Standardized progress reports are easy to grade.<br>• Objective score cards: ABET learning objectives (guidelines).<br>• Easy to demonstrate ABET compliance, and report results back to the department. | • Ability to informally track progress without excessive handholding (e.g., through the online message board).<br>• Formal progress reports (standardized structure; easy to locate content of interest) |



## Requirement Gathering

The first stage towards achieving this goal involved Requirement Gathering. During this stage, the team clearly articulated the problem statement, defined the customers (listed in Figure 2), and formulated the customer and engineering requirements (per Figure 3). This step included extensive conversations with the BAJA team to characterize its exact needs. Thorough research was performed to ensure that the design could be pursued in accordance with proper requirements [4, 5].

**FIGURE 2** Customer Definition tab from the e-design notebook.

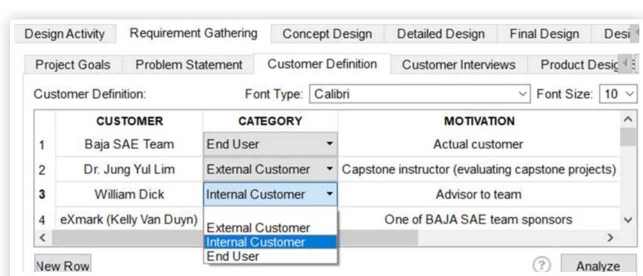
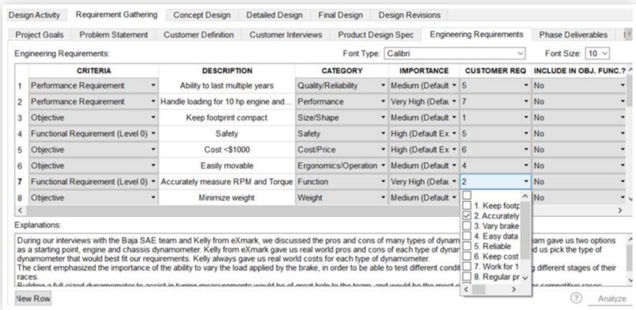


**FIGURE 3** Engineering Requirements tab from the e-design notebook.






## Concept Design

During the second stage, Conceptual Design, a general solution for the dynamometer began to take shape. The team performed an analysis on the designs considered for the type of dynamometer, and the type of brake, to be used (see Figure 4). The team analyzed how the dynamometer should measure the output torque and rotational speed (RPM), and what type of data acquisition best suited the application. The team performed a functional decomposition to further identify specific dynamometer requirements. Additionally, Pugh decision matrices were completed to compare possible design components and assist in choosing the said components. From these analyses, the capstone team settled on a solution it believed best alleviated the BAJA SAE team's problem: The capstone team decided to construct an *engine dynamometer with a disc brake*. A load arm would be used to apply the load from the brake to a force sensor. The output of the force sensor, as well as a proximity sensor for RPM data, would be read using an Arduino processor for data acquisition. Sketches were made by hand of the overall dynamometer and the load arm assembly [4, 5].

## Detailed Design

The third stage was the Detailed Design phase, where the team performed necessary force and torque calculations to ensure proper choice of mechanical components that were rated for these loads. A schedule was created, that captured the start and finish dates for various tasks - ranging from the first day of initial research to the team's final presentation (see Figure 5). A Failure Modes and Effects Analysis (FMEA) was performed on each mechanical component to prevent overlooking design errors that could cause failure of the dynamometer. The Detailed Design was also the stage where the initial design of each component began. SolidWorks was utilized to create 3D models, which were loaded into an assembly to investigate mating issues and general size constraints. The following models were created: load arm, base plate, driveshaft, and load cell block. Finite element analysis was performed on the driveshaft. Other components were analyzed but not drawn in SolidWorks because they could easily be purchased, and did not require external manufacturing [4, 5].

**FIGURE 5** The high-level project schedule produced by the team.

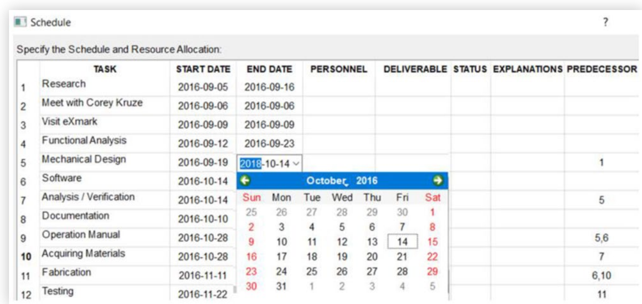
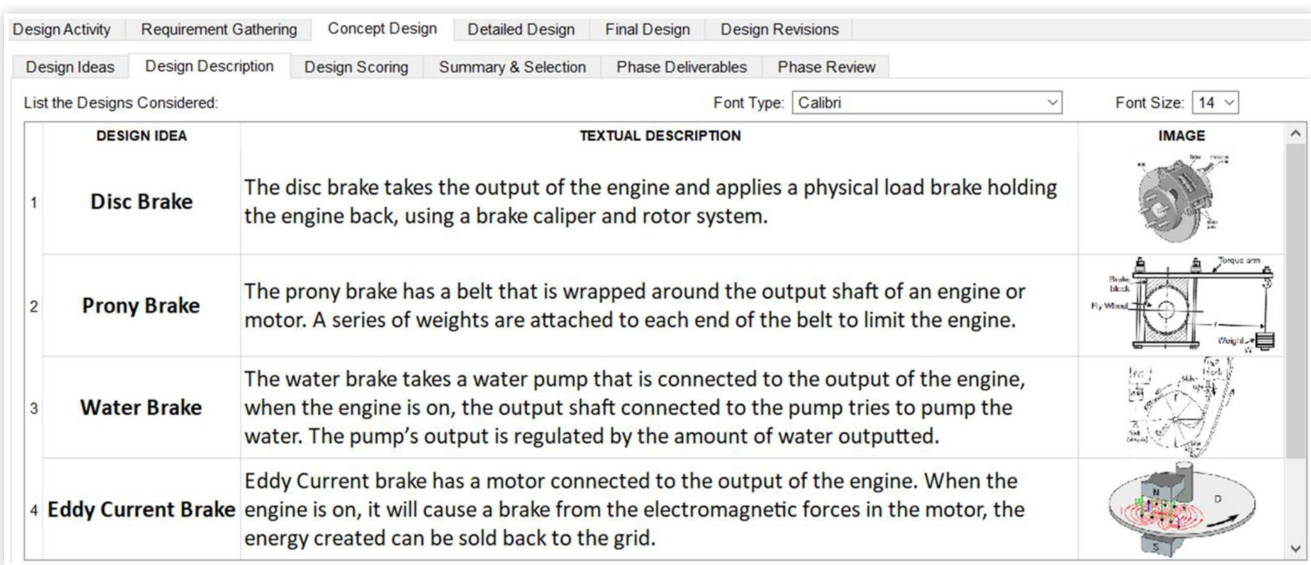





**FIGURE 4** The Ecosystem 1.00 SW enables succinct textual and graphical description of the design ideas.



## Final Design

The last stage was the Final Design phase. In this phase, all designs were edited and completed so that the team could begin fabrication. Due to time constraints related to shipping, equivalent bearings were selected that could be delivered on time. It was determined that the rotor would not be sufficient for use with the proximity sensor, so a sprocket was designed for compatibility. As a result of this, the driveshaft was extended to allow room for the sprocket to be mounted. The load arm was completely redesigned, now consisting of two thin steel components - one specifically for reinforcement. The hardened contact pin was placed in a cut-out in the transverse direction at the end of the arm. The base plate was also switched to thinner steel, and angle iron was added around the perimeter of the plate, to raise the height from table level. This was done to make it easier to access the underside, and for additional deflection support. To obtain increased accuracy at a lower cost, the force sensor was changed to a capacitive type. A new data logger was chosen, and the rotor switched to thicker steel [4, 5].

## Prototype Delivered

In the end, nearly all of the project objectives were accomplished. Figure 7 presents a side view of a proxy sensor mount, brake caliper, and load arm layout. Video showing the prototype in action can be accessed through [5]
http://www.imagars.com/applications-ecosystem/.

## Set-Up and Execution

Table 2 summarizes the set-up and execution of the Dynamometer project (a MECH 447 project). Overall, the Ecosystem design framework provided a good fit to the needs of the Dynamometer team. Further, during the course of the capstone project, the Dynamometer team received considerable support on the Ecosystem, for example, on how to run it under Macintosh.

## Results and Observations

The Dynamometer project mapped very well to the Ecosystem. In addition to the features for the analysis and verification of the requirements and concept designs, per Figures 2 - 3 and Figure 6, the team made extensive usage of the Meeting Notes and Customer Interview functionalities. Judging from the final report, it appeared the ability to export the content of these sections into a formatted report proved very useful.

## Features the Team Found Most Useful

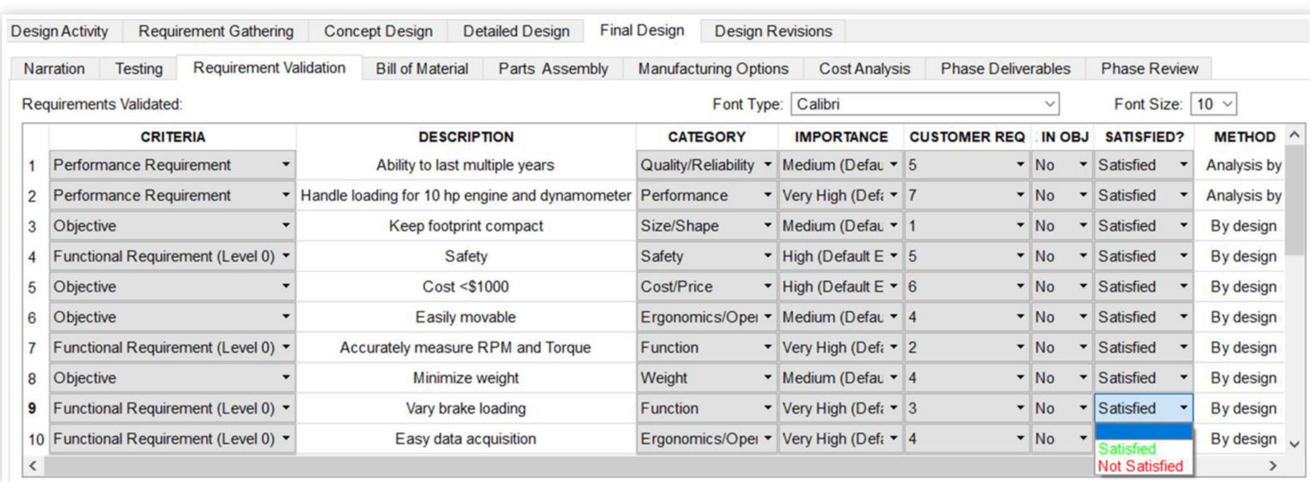
In an evaluation report submitted at the end of the project, the team listed the following:

1. "Detailed outline helped us understand each component for a design report."
2. "The extensive user manual gave useful instruction on how each tab operates."
3. "Ability to export the document allowed us to make any necessary changes in [MS Word]."
4. "Examples of previous reports in [Ecosystem] helped us understand the information to be included for each tab."

**FIGURE 7** Side View of Proxy Sensor Mount, Brake Caliper, and Load Arm Layout [5].



**FIGURE 6** The Ecosystem 1.00 SW helped the Dynamometer team validate its engineering requirements.




| | CRITERIA | DESCRIPTION | CATEGORY | IMPORTANCE | CUSTOMER REQ | IN OBJ | SATISFIED? | METHOD |
|---|---|---|---|---|---|---|---|---|
| 1 | Performance Requirement | Ability to last multiple years | Quality/Reliability | Medium (Defau | 5 | No | Satisfied | Analysis by |
| 2 | Performance Requirement | Handle loading for 10 hp engine and dynamometer | Performance | Very High (Defa | 7 | No | Satisfied | Analysis by |
| 3 | Objective | Keep footprint compact | Size/Shape | Medium (Defau | 1 | No | Satisfied | By design |
| 4 | Functional Requirement (Level 0) | Safety | Safety | High (Default E | 5 | No | Satisfied | By design |
| 5 | Objective | Cost <$1000 | Cost/Price | High (Default E | 6 | No | Satisfied | By design |
| 6 | Objective | Easily movable | Ergonomics/Opei | Medium (Defau | 4 | No | Satisfied | By design |
| 7 | Functional Requirement (Level 0) | Accurately measure RPM and Torque | Function | Very High (Defa | 2 | No | Satisfied | By design |
| 8 | Objective | Minimize weight | Weight | Medium (Defau | 4 | No | Satisfied | By design |
| 9 | Functional Requirement (Level 0) | Vary brake loading | Function | Very High (Defa | 3 | No | Satisfied | By design |
| 10 | Functional Requirement (Level 0) | Easy data acquisition | Ergonomics/Opei | Very High (Defa | 4 | No | | By design |

5. “Hovering over any section brings up a description of each section; this allowed us to save time to understand each section.”
6. “The ability to insert information into meeting minutes, information sources, and deliverables into each design phase allows the user to save time.”
7. “The user interface was easy to understand a nd allowed the user to insert information quickly and painlessly.”

## Suggested Improvements

1. “No spell check leads to user error.”
2. “When meeting minutes are archived, I tried to edit the information in the archive and it would not save my changes. Allowing previously archived info to be edited would be beneficial and save time.”
3. “When exporting the report to an HTML or ODF file, tables sometime [sic] did not export correctly. We had a few instances where the table would export completely without the last column. Also the header of the table also got jumbled around to different columns.”
4. “We also had issues when exporting the document to an ODF file; the figures would lose their file path and would just show a question mark in the figure.”
5. “Each design project is different from one another. Allowing each tab to be able to insert figures would aid in the report generating process.”
6. “Many institutions require references to be in MLA, APA, or different formats. Information Sources tab should allow the user to insert full sources into the section.”

**TABLE 2** Ecosystem alignment with the set-up and execution of the Dynamometer project.

| Project Aspect | Team Approach | Ecosystem Alignment |
|---|---|---|
| Customer definition & interviewing | Extensive customer interviews | Very good (see Figure 2). Customer interview tab with ability to export content into formatted report. |
| Concept design | Design outline, Functional decomposition | Nice features for design description and functional decomposition (Figure 4). |
| Solid modeling | SolidWorks | Ecosystem provides an interface to SolidWorks. |
| Finite element analysis | SolidWorks | Ecosystem provides an interface to SolidWorks. |
| Scheduling | Traditional | Very good (see Figure 5). |
| Requirement Validation | Traditional | Very good (see Figure 6). |
| Team communication | Weekly in-person meetings | Team made extensive usage of the Meeting Notes tab and exported into a formatted report. |
| Personal computing | Windows and Macintosh | Team utilized the Winebottler utility to run Ecosystem under Macintosh. |



## Overall Value Added

Towards the end of the project, the team’s faculty advisor noted:

*“I have only two teams and they both have performed admirably. The Dynamometer team has managed to stay on schedule a little better but I’m not certain whether that is due to Ecosystem or some other factor.*

# Improvements Resulting from the Evaluation

## Improvements Already Addressed

Many of the improvements suggested by the Dynamometer team were fairly easy to address. The team’s evaluation report prompted the following:

1. The problem with editing of the archived meeting minutes was fixed.
2. Headers were properly displayed in exported reports.
3. Explanations were added related to the exported HTML reports being compatible with MS Word.
4. OpenOffice Writer was listed as the recommended tool for viewing figures in ODF reports.
5. The formatting of the tables and figures in the exported reports was much improved.

## Improved Instructor Features

We believe improvements to the instructor functionalities can generally be categorized as follows:

1. Improved facilities for team formation.
2. More complete reporting of ABET learning outcomes.
3. Accurate assessment of individual student contributions within the team function.

# Conclusion

The Ecosystem for Learning and Team Design has proven to offer a very good fit to the design process taught in the Department of Mechanical and Materials Engineering at the University of Nebraska-Lincoln. In the end, the capstone team working on the Dynamometer for Centrifugal Clutch Tuning project accomplished nearly all of its objectives, and the team managed to stay on schedule a little bit better than the other capstone design team managed by the same faculty advisor.

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