



Evaluation of Ecosystem for Design Assessment and Verification by the Formula and BAJA SAE Teams at the Oregon Institute of Technology

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Citation: Collins, R.L., Stover, C.M., Moravec, B., and Steingrímsson, B., "Evaluation of Ecosystem for Design Assessment and Verification by the Formula and BAJA SAE Teams at the Oregon Institute of Technology," SAE Technical Paper 2020-01-0490, 2020, doi:10.4271/2020-01-0490.

Abstract

This paper summarizes the outcome of an evaluation by the Formula and BAJA Society of Automotive Engineers (SAE) student design teams from the Oregon Institute of Technology of the Ecosystem for Design Assessment and Verification. The Ecosystem is a design decision support tool whose main goal is to identify design oversights early in the design process, guide designers through the design process, and foster high-quality design practices. The Ecosystem offers many features attractive to Formula and BAJA student design teams. It is capable of capturing and archiving design work, including the rationale for design decisions, and making searchable. It enables new design teams to rapidly get up-to-speed, and helps with *knowledge transfer*. In the case of Formula or BAJA SAE, the Ecosystem allows the design teams to quickly acquaint themselves with the work left behind by previous student teams, such as the opportunities for improvement identified.

A primary observation from the paper pertains to the importance of helping student design teams adapt the Ecosystem to their file archives. In addition to receiving the

Ecosystem software, the students need support in order to effectively use the Ecosystem in conjunction with the existing file archives. In case of a BAJA student design team from Oregon Tech in Wilsonville, a new team with no legacy archives, we have found it effective to sit down with Secretary of the team, in order to educate the Secretary on how the Ecosystem can help document the design and building of the car, so that future teams can learn about the process that went into the design decisions made. Similarly, in case of Formula and BAJA student design teams from Oregon Tech in Klamath Falls, we intend to sit down with the Vice Presidents of the teams, for same purpose. We are helping the teams better organize their design repositories and access through the Ecosystem. While students welcome the pre-populated checklist for the technical inspection, along with facilities for part management and planning for manufacturing, we have come to recognize the importance of providing good support, for the students to effectively use the Ecosystem. Providing good support from year to year is important, since the teams' composition, and familiarity with the Ecosystem, may change significantly between years.

Keywords

Design process, design competition, design assessment, ABET learning outcomes, productivity improvements,

Introduction

Problem Statement

Many Oregon Tech Mechanical and Manufacturing Engineering and Technology (MMET) students participate in either the BAJA SAE or Formula SAE competition for their year-long Senior Projects. These students are also supported by undergraduates from both the MMET Department and from other departments such as Management, Electrical

Engineering and Computer Software. Each team will spend up to 10,000+ hours during the academic year designing, building, testing, creating marketing studies, and finally racing their finished vehicle. The design of these vehicles is complicated, involves many different components, and is constantly being revised to meet new rules and team goals. The rules for each competition vary from 124 pages for the BAJA SAE competition [1] to 132 pages for the Formula SAE competition [2]. *Keeping track of the vehicle design, making*

FIGURE 1 Oregon Tech recent Formula SAE and BAJA SAE vehicles (photos by B. Moravec).



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sure the vehicles meet the rules, and documenting this information for future teams was proving to be an ever-increasing challenge. Recent Oregon Tech Formula SAE (FSAE) and BAJA SAE (BSAE) competition vehicles are shown in [Figure 1](#) above.

Previous Student Documentation

Previously, students documented their ideas in bound notebooks and in design reports. [Figure 2](#) below shows just a few

FIGURE 2 Multiple notebooks containing design data (photo by B. Moravec).



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of the notebooks collected in recent years. *With hundreds of parts in the manufacture of the BAJA SAE and Formula SAE cars, it was becoming increasingly difficult to manage all of the design ideas.*

Ecosystem for Design Assessment and Verification

The Ecosystem for Design Assessment and Verification software was developed by Imagars LLC through Small Business Innovative Research (SBIR) Phase I, Phase II and Phase IIa grants from the National Science Foundation (NSF). This software guides designers through the design process in a structured fashion, supports the learning of proper design techniques, and helps eliminate design oversights. Other benefits of using this software include:

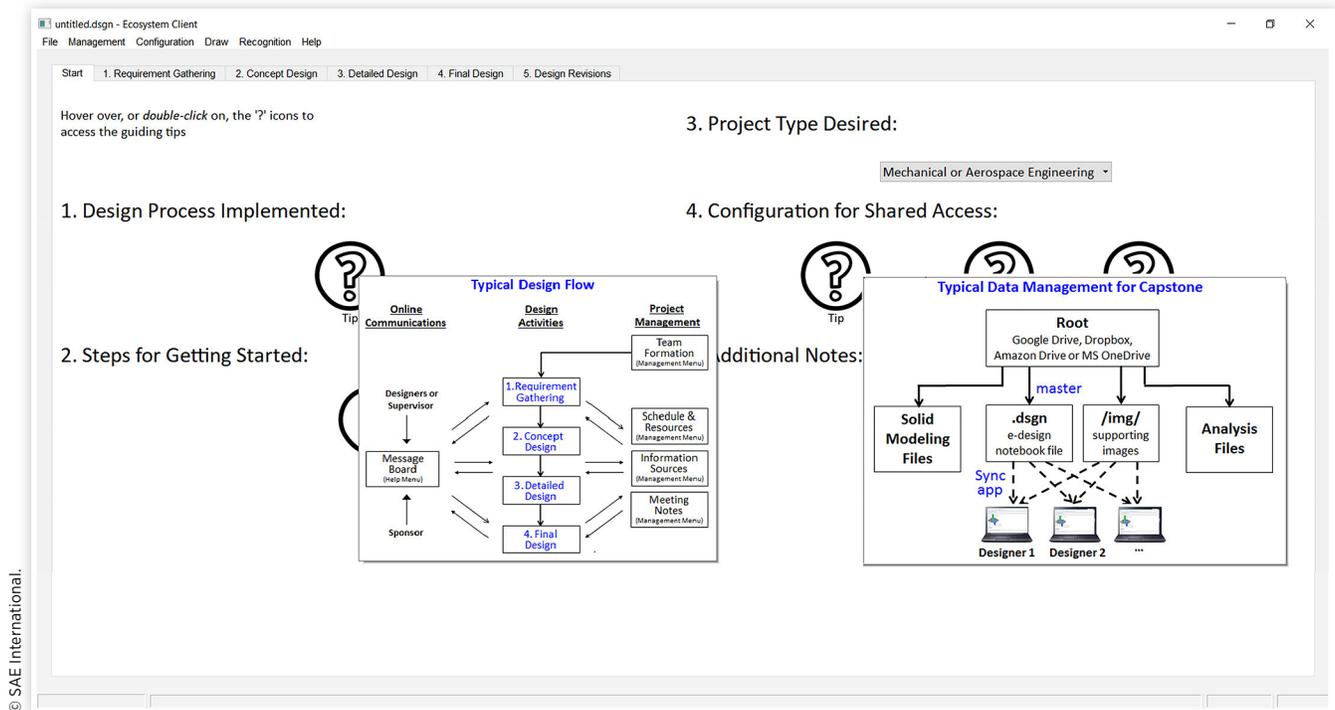
- The software supports learning outcomes derived from learning outcomes for engineering design by the Accreditation Board for Engineering and Technology (ABET).
- The software offers automatic & objective scoring of design concepts relative to the design requirements.
- The software provides multiple features aimed at facilitating communications within design teams.
- The software facilitates project and part management, along with the project schedule.
- The software serves as an electronic notebook of the comprehensive design history.

A free trial version of the software may be obtained by visiting the following website:

<http://www.imagars.com/>

This new software allows the student teams to gather all of their data from separate notebooks and store in a common file. It has been created in order to provide a structured environment to guide students through the design process, and to reduce the chance of encountering an expensive oversight. Some valuable features of the software include the incorporation of assessment of the ongoing design activities (including ABET-compliant learning outcomes), the ability to store in one place the rationale for design decisions (which *greatly helps with knowledge transfer* for on-going projects, such as for the BAJA and Formula SAE teams), and automatic generation of formatted project reports.

A screenshot from the start-up menu of the Ecosystem program is shown in [Figure 3](#) below. The program follows a familiar multiple-tab arrangement, with many options available to the user. For smaller projects, some of the functionality of the software can be hidden from the user to facilitate (simplify) the learning process. Tabs can be deselected to customize the software for the project at hand.

FIGURE 3 Start-up menu from Imagars software.

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For further background on the Ecosystem, in context with the state-of-the-art in knowledge management applied to engineering design, refer to [3, 4, 5, 6], and the references therein.

Reasons for Adoption

Experience of the BAJA SAE Team at the Competition in Gorman CA in April 2017

The BAJA team found it challenging to explain to the design judges, in the limited time provided, what was so special about the design of their subsystems:

1. The team had hard time communicating their analyses in a clear and concise fashion.
2. Some of their finite element analysis (FEA) files may have been missing from their progress report.

Furthermore, the BAJA team ran into problems that could have been prevented relatively easily back at Klamath Falls, by checking their vehicle against the judges score sheet:

1. The BAJA team experienced problems related to a leaking gas tank.
2. The team tried to combat it by applying three rolls of tape.

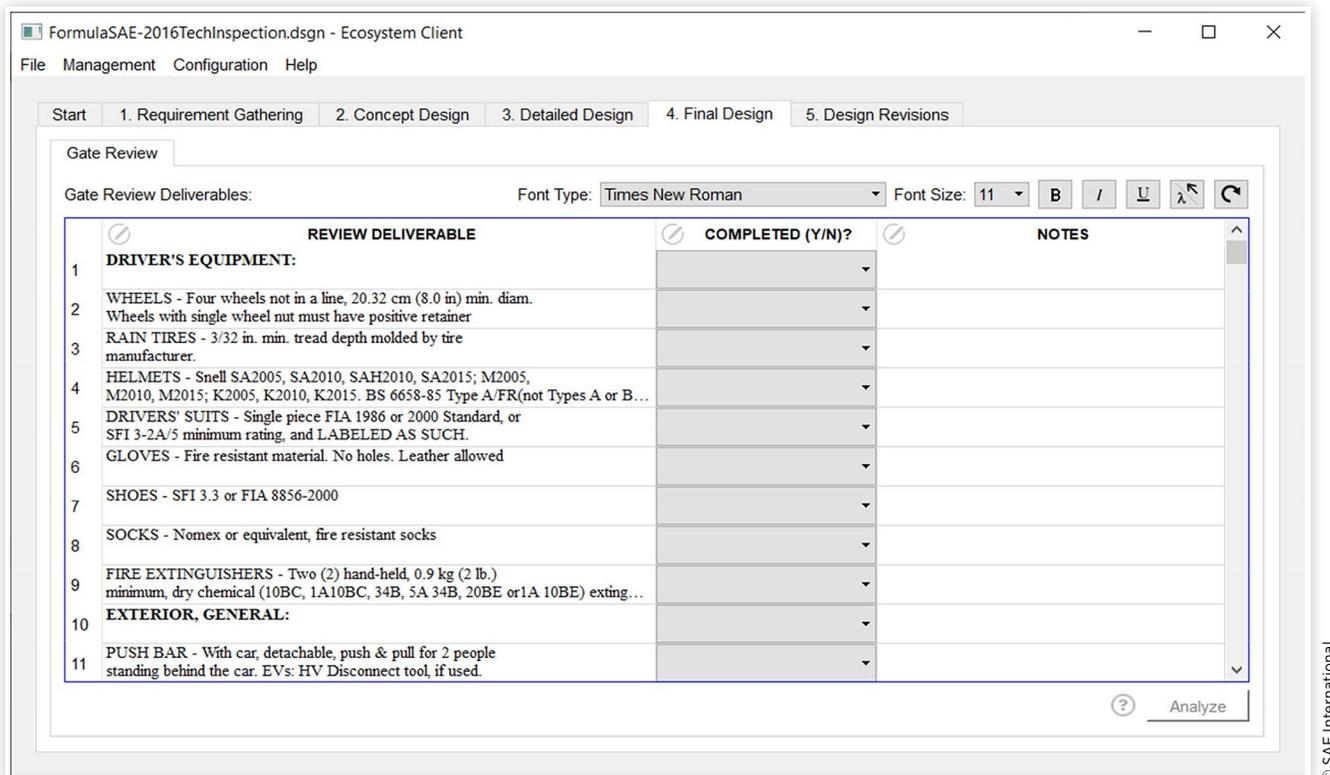
The team believed it could have passed tech inspection more easily, if the team had checked their vehicle against the score sheet of the design judges, prior to heading for competition.

Experience from the Formula Team at the Competition in Lincoln NE in June 2017

The Formula team performed below expectations, largely due to lack of documentation, combined with absence of key personnel. The lead for suspension and frame contacted the faculty adviser, early in the morning on the day when the team was set to leave for Lincoln, and told the adviser he could not go. This left the faculty adviser in tough situation, because the suspension and frame systems had not been fully documented, and there was nobody to step in, esp. not on such a short notice. The faculty adviser thought the Formula team would have made it to the design finals, if this had not come up.

Pre-Populated Check List for Tech Inspection from the SAE Rulebook

Per suggestion from the faculty adviser, Imagars incorporated into the Ecosystem examples capturing the score sheets of the tech inspectors at the Formula and BAJA competitions, respectively. Figure 4 above provides a glimpse into the checklist of the tech inspectors incorporated into the Gate Review tab from the Final Design phase of the Ecosystem.

FIGURE 4 Excerpt from check list from the tech inspectors at Formula competition captured in the Ecosystem.

Tools Enabling Students to Manage Parts and Prepare for Manufacturing

The Ecosystem provides facilities aimed at helping student design teams keep track of the parts, that go into the race car, but also helps students prepare for manufacturing. [Figure 5](#)

presents a bill of material that has been imported into the Ecosystem from SolidWorks. [Figure 6](#) presents a corresponding snapshot from the Manufacturing tab of the Ecosystem. The Ecosystem allows students to compare the cost of in-house manufacturing to that of outsourcing, for each part manufactured (or for each step in the manufacturing of a given part).

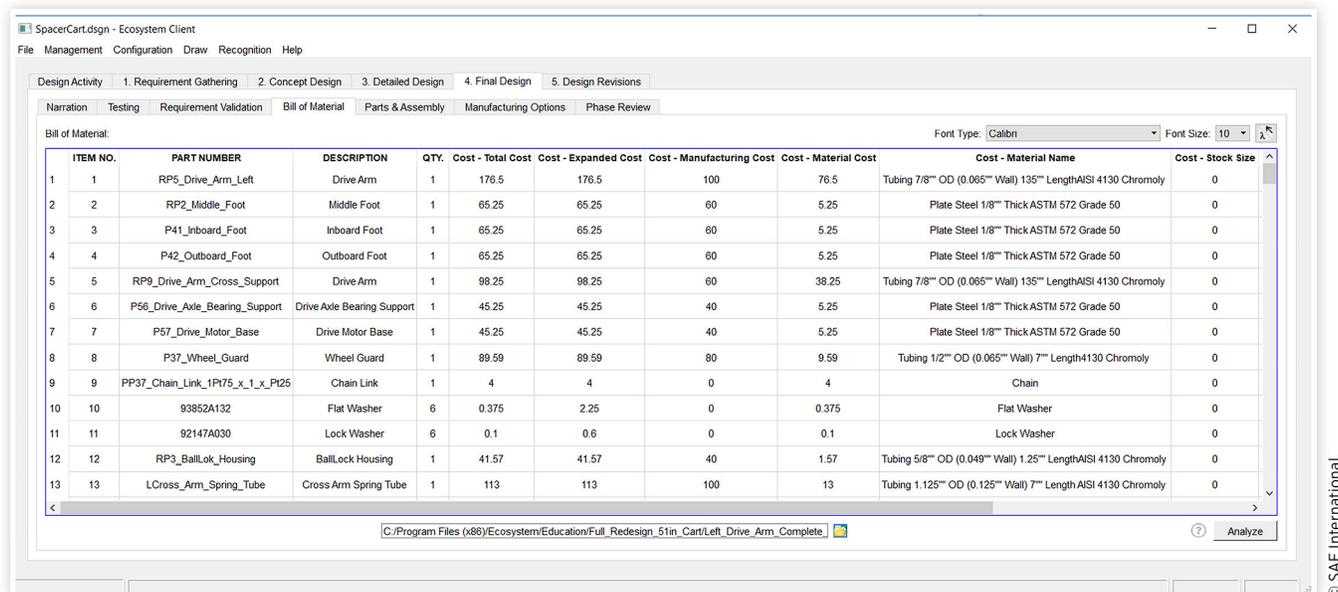
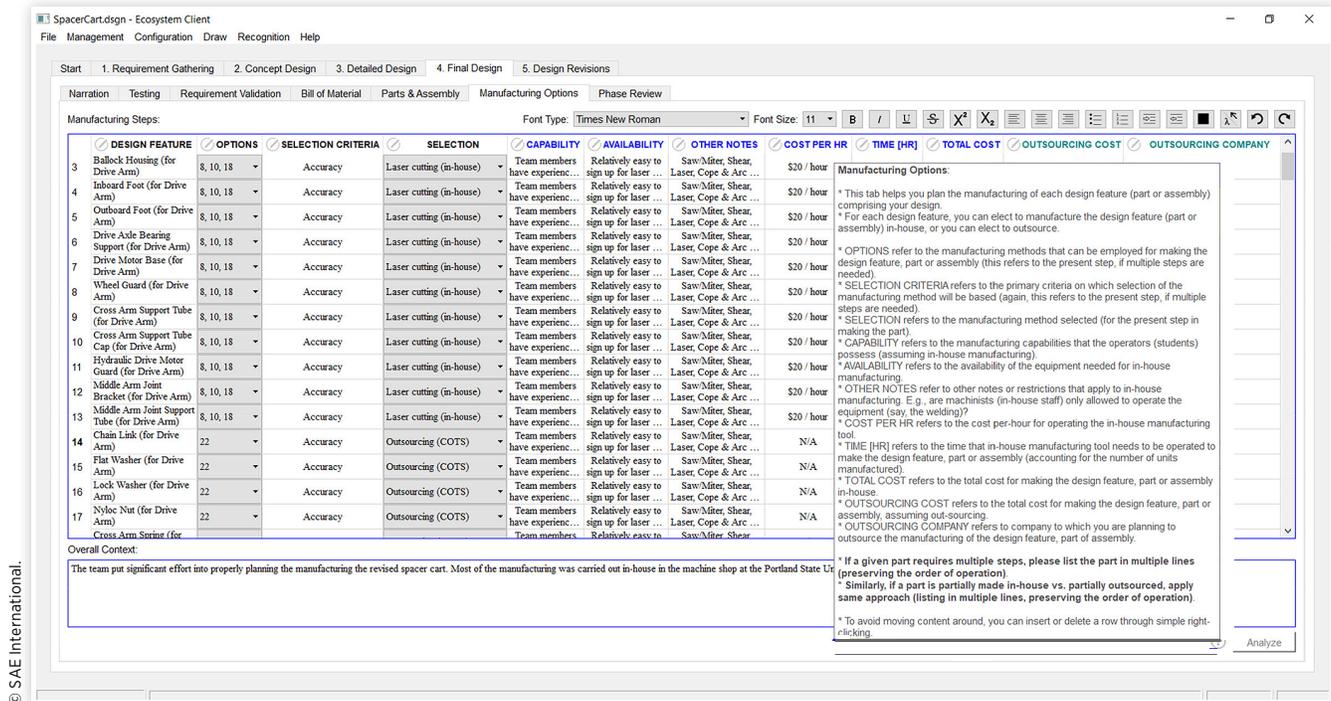
FIGURE 5 The Ecosystem has the ability to import bills of material from SolidWorks assembly, part or drawing files.

FIGURE 6 The Ecosystem provides facilities aimed at helping students plan for manufacturing.

Ability to Link FEA Results into the Calculations & Analysis Tab

The BAJA team was quite encouraged to discover the ability to link FEA files into the Calculations & Analysis tab of the Ecosystem. The team liked the fact that the images imported were included in the exported reports. This could facilitate clear, concise and effective presentation of the risks analyzed to the design judges. The students looked at the Ecosystem as a tool that could help them effectively convey, within the limited time they had in front of the design judges, what was great about their subsystem designs.

Automatic Generation of Nicely Formatted Project Reports

The Ecosystem provides facilities for automatically exporting students' design content into nicely formatted, Word-compatible .html reports, such as the ones that the judges look at during competition.

Automatic Assessment against ABET Learning Outcomes

The automatic assessment against the ABET learning outcomes is of interest to the broader Oregon Tech faculty that teach the senior design classes in the MMET department. The Ecosystem provides automatically populated score cards capturing the scoring of students' design work against the ABET learning

outcomes 1 - 7 for Engineering Accreditation (EAC). Of specific interest to Oregon Tech faculty are the ABET learning outcomes 1 - 5 for Engineering Technology Accreditation (ETAC). Imagars' intent is to help design faculty and academic departments expedite the data collection process needed for ABET reporting.

Experience from Evaluation of Imagars' Software

The 2016 - 2017 Academic Year: Initial Exposure - Ecosystem Presented as Optional Tool

In 2016 - 2017, the Ecosystem was provided to the Formula and BAJA teams as an optional tool. Adoption was somewhat slow, in part because the Ecosystem was introduced after the academic year had started.

The 2017 - 2018 Academic Year: Beta Testing - Bonus Points at Competition in Washougal WA

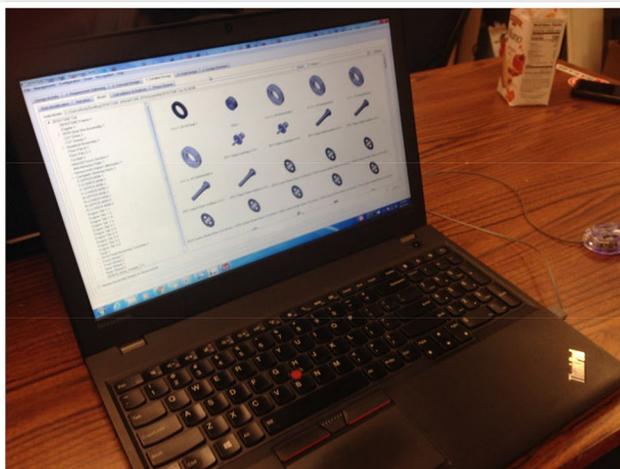
Oregon Tech Racing (OTR) was one of several university racing teams that Beta-tested the Imagars software during the 2017 - 2018 competition season.

The main reasons why OTR adopted the Imagars software were to:

- Help guide the students through the design process. Both the BAJA SAE and Formula SAE competitions place a high importance on students following all of the necessary steps of the design process.
- Help to document the work that the students did so that future teams will both have a copy of the part designs, plus all of the background on why the particular design was used.
- Serve as a presentation platform at the competitions during design judging. *For the 2018 BAJA SAE competition the OTR team was awarded innovation bonus points for using Imagars' software; plus the Ecosystem helped the team organize their material during the design judging, which also earned them additional points.*
- Help with component integration: With many different vehicle systems involved (engine, frame, suspension, drive train, braking, steering, ergonomics, electrical, etc.; each with their own Imagars' e-design notebook file), a new System Integration group was formed. This group was responsible for making sure that all of the vehicle systems worked together. Assigning a separate e-design notebook file to each sub-system helped make this successful.

The Ecosystem served the students well in preparation for the BAJA competition in the Washougal WA towards the end of May 2018 (see [Figure 7](#)). Imagars' logo was featured on the team's vehicle, as shown in [Figure 8](#). *The design judges liked the organized presentation by the students, as well as the usability features, enough to award the BAJA team with bonus points for their use of the Ecosystem software.* The design judges liked the way the students walked them systematically through the design work, compared and contrasted design options, and highlighted the rationale for design decisions made. The design judges also liked the expanded view of the images, that showed

FIGURE 7 From students' use of the Ecosystem software during the 2017 - 2018 academic year (photo by B. Steingrímsson)



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FIGURE 8 The vehicle racing at the BAJA competition in Washougal in late May 2018 featured Imagars' logo (photo by B. Steingrímsson).



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up, upon double-clicking on design drawings of interest. The students seemed quite satisfied, since the bonus points served as a measure of instant reward for their use of the Ecosystem.

In the fall of 2018, the faculty adviser gave a poster presentation of the team's experience from the competition in Washougal at the 4th Annual Commission on College Teaching Conference. The Conference took place at the Oregon Institute of Technology on September 17, 2018. The presentation attracted interest, such as from Andria Fultz, who is an Associate Professor in Communications at Oregon Tech. But she also helps the RockSat rocket satellite club, which is a big student club at Oregon Tech in Wilsonville. She thought the Ecosystem would help standardize efforts across project teams.

The 2018 - 2019 Academic Year: Plans for Offering Proper Training in Klamath Falls

Heading into the 2018 - 2019 academic year, the Formula and BAJA teams were planning continued use of Imagars software. In order to increase effectiveness in using the software, the following actions were planned:

1. The teams were planning to use the software from the beginning of fall 2018 term.

2. A sample design was being created during the summer of 2018.
 - The plan was to use this sample design for giving weekly lectures throughout the academic year on various features of the software.
3. Students would be required to update their files weekly, which hopefully would help students better adhere to their project's schedule.
4. The design software would be used for creating posters for each major component of the vehicles.
 - These posters would be brought to competition and shown to the design judges.

In practice, the incoming students proved to be much less motivated about the Ecosystem than the students from the previous year. Even though Imagars had added a spell checker to the Ecosystem, per suggestion from students from the previous spring, it did not seem to make much of an impression on the new group of students. The effort needed to get up to speed with the Ecosystem may have come across as daunting. The new group of students seemed more inclined towards continued use of the old legacy documentation system (Google Docs and Powerpoint presentations). We sensed significant change resistance, which probably could have been addressed by providing proper training, if we had anticipated in advance this change in perspectives between years. The faculty adviser noted he had made similar observations in the advent of Computer Aided Design (CAD). At the time, engineers had questioned the need to change. After all, they had invested a lot of work in the old fashioned drawings.

The BAJA team seemed to express renewed interest in the Ecosystem, at the competition in Gorman CA in mid-May 2019, when Patrick Ponticel, Editor of the MOMENTUM, the magazine for and about student members of SAE International, stopped by at their repair tent, to ask questions about OTR's use of the Ecosystem software (and to take some photos). Just the month before, Patrick Ponticel had reached out to Imagars, in regards to a presentation at the 2019 SAE World Congress on use of the Ecosystem by the University of Nebraska in Lincoln. This photo opportunity seemed to spur much more favorable impression of the Ecosystem.

Last but not least, we came to learn, in the fall of 2018, that people within Oregon Tech in Wilsonville had interest to start a separate BAJA team, lead by Prof. Cliff Stover. Towards the end of November 2018, Prof. Stover indicated he would have better sense, by summer 2019, of the extent of student participation, and the extent of support from the university administration.

The 2019 - 2020 Academic Year: Further Training - Extension to Wilsonville Campus

1. Oregon Tech Off-Road BAJA SAE in Wilsonville OR

By early fall 2019, we came to learn that the BAJA team at Oregon Tech in Wilsonville had officially been launched.

Through communications with Prof. Stover, we came to realize the following:

1. The team had been given the title Oregon Tech Off-Road.
2. Oregon Tech Off-Road had registered for the competition which will take place in Peoria IL on June 3 - 6, 2020.
 - The team had registered for the last competition in the year 2020, because it needed time to build and test their vehicle.
3. Prof. Stover was concerned about the students' deadlines and deliverables for the competition.
4. The students were very constrained on time
 - Many of the students were taking multiple classes, and working part-time, and also participating in the BAJA team.
5. The BAJA team was using management and analysis software that the students had agreed on using.
6. An appropriate route forward would involve communications with the Secretary of the team, not the whole team.
 - The Secretary would be the team's liaison with the Ecosystem.
 - The Secretary had been tasked with looking into documentation on the Ecosystem, familiarizing himself with the process provided by the Ecosystem, and conducting an evaluation.
7. Since the team was starting from scratch, there obviously was no legacy documentation to worry about.

Through correspondence with the Secretary of the BAJA team in Wilsonville, we were further appraised of the following plans:

1. Plan for building infrastructure that enables the team to educate new members on what was required, to make the team successful.
 - Since the BAJA team is a first year team, they think this will be very important to their overall success.
 - This plan may need support or participation from the business department at OIT (for fundraising, sales presentations, etc.).
 - The BAJA team intends to recruit from the business majors at OIT.
2. Plan for teaching new members the fundamentals of the car itself.
 - Some of the freshmen coming in from high school are lacking essential familiarity with standard vehicle components.
 - The BAJA team intends to recruit freshman and sophomores.
 - So the student leaders on the BAJA team are planning to put together an in-house curriculum that teaches the underclassmen what the components of the car are for, and what they do.

3. Plan for documenting the design and build of the car, so that future design teams can acquaint themselves with the thought process that went into the design decisions made.
 - Here the Ecosystem comes in.
 - The Secretary favored creating a technical paper for each component design, one that explained why the team designed a given component in a particular way.
 - The Secretary thought this - along with computer aided designs (CADs) and testing results - may be foundational to the team's success.
 - *It can be added that this vision aligns quite well with the Ecosystem framework.*
 - *Each technical paper could map to a separate e-design notebook file.*
 - The Secretary acknowledged that the vision of a technical paper for each component design was quite an endeavor and required work that the BAJA team might or might not be willing to conduct.
 - *Imagars intent is to help the BAJA team find the best way to carry out this plan, and support the team through the execution.*

2. Oregon Tech Racing in Klamath Falls OR

During Imagars' October 26 2019 visit, the Formula and BAJA teams in Klamath Falls resonated much of the sentiments expressed by the BAJA team in Wilsonville. The Formula and BAJA teams in Klamath Falls noted that they did not have a Secretary, but the Vice President would likely be an appropriate point-of-contact. They noted that their design information was not organized very well on their Google Drive, and students were sometimes lead down a wrong path. At times, students didn't find the design information they were looking for. The students of Oregon Tech Racing also offered great suggestions on how to extract requirements from the BAJA and Formula SAE rulebooks [1, 2], incorporate into the Engineering Requirement tab of the Ecosystem, and express dependencies. Overall, Imagars came to recognize the importance of providing good support, with regards to helping students integrate the Ecosystem into their program. Imagars will be looking to make an appointment with the Vice Presidents of the Formula and BAJA teams in Klamath Falls, similar to the one with the Secretary of the BAJA team in Wilsonville, probably towards the end of 2019 or in early 2020.

Suggested Further Improvements

Further Pre-Populated Material from the SAE Rulebook

The faculty adviser of the Formula and BAJA teams in Klamath Falls has pointed out the inconvenience of large paper archives. He has noted the SAE Welcome package has become quite

voluminous. He has, further, indicated that the printed version of the schedule from previous years used to be up to 15 feet in length.

Formula or BAJA SAE teams from Portland State University (PSU), California State University (CSU) in Northridge and the New Mexico Institute of Mining and Technology have similarly encouraged Imagars to capture content, in addition to the check list presented in Figure 4, and include with the Formula and BAJA examples that ship with the Ecosystem software. Imagars intends to augment these examples, such as to include

1. Design requirements for individual sub-systems.
2. Information from the cost report.
3. Information aimed at helping students prepare for their business presentations.
 - This could include a profile description for the customer targeted captured in the Customer Interview tab of the Ecosystem.
4. Deadlines for deliverables leading up to competition.

Web Page Highlighting Recent Enhancements of Examples and Changes to the Rulebook

Changes to the rulebook tend to be of great interest to the students, since such changes are likely to affect their total number of points earned during competition. As an example, at the 2020 BAJA competitions, the 4-wheel drive traction system will be optional, but it will be required at the 2021 competitions. The change from rear wheel drive to an all-wheel drive is a major change in the BAJA rulebook. For purpose of effective communications with the students, Imagars intends to present samples from the check list for the tech inspectors in a web page, linked to its website, and highlight the relevant changes. We think this will help in making the Ecosystem more relevant to the students.

Introducing Ecosystem Software in a Simplified Form in Freshman Orientation Classes

The faculty adviser, Prof. Moravec, has recommended presenting the Ecosystem in simplified form in freshman orientation classes, by hiding tabs of lesser importance to begin with. As students gain familiarity and proficiency with the Ecosystem, the lesser important tabs can be re-enabled. Then, when the students do their senior projects, they will be used to the full tab structure. Prof. Moravec thought, if the students got exposed to all of the tabs, in a short amount of time, the learning curve might prove to be too steep. Hence, one of the things we are considering involves a gentler approach to helping students acquaint themselves with the Ecosystem, through smaller learning steps.

Key Learning Lessons

Continuity from Year to Year Is Essential

Transfer of tribal knowledge from year to year, as key people graduate and leave, is a primary reason as to why faculty advisers have encouraged Formula or BAJA teams to adopt the Ecosystem software.

Examples with Pre-Populated Content Welcomed

Students have tended to welcome the examples with pre-populated content from the Formula or BAJA SAE rulebook.

Bonus Points Have Served as Significant Motivation

The prospect of students earning bonus points at competition, for their use of the Ecosystem, has served as a strong source of motivation.

Change Resistance in Case of Legacy Documentation

In certain cases involving significant legacy archives, students have resisted adoption of the Ecosystem software. Here, the path of least resistance may entail duplication of past efforts. In case of the 2018 - 2019 OTR team, this included continued reliance on Google Docs, Powerpoint presentations and paper notebooks.

Working with Teams' Secretaries May Be Effective

As opposed to targeting entire teams, it may be more effective to sit down with a key individual responsible for organizing the documentation of a given Formula or BAJA team. In case of the BAJA team in Wilsonville, this was the team's Secretary, but in case of the Formula and BAJA teams in Klamath Fall, it was the Vice President. We have found out that in addition to the Ecosystem software itself, students may need good, on-going support, in order to smoothly and effectively use the Ecosystem together with their existing design archives.

Conclusions

The Beta testing of the Ecosystem for Design Assessment and Verification is continuing. Benefits of using this software

include better communication and continuity between years (transfer of tribal knowledge), a more complete documentation of the design work by the students, and a structured environment throughout the design process. A major hurdle to overcome for existing teams has been the reluctance of some team members to use a different process than was used in the past (Google Docs and paper notebooks). We have overcome this - in part - by working with a key member responsible for organizing the documentation, for the Formula or BAJA teams involved, as opposed to targeting all team members, and by providing good support. Once we have polished our approach for supporting the Formula and BAJA teams, we think there will be other opportunities for the Ecosystem within Oregon Tech, such as with the RockSat rocket satellite club and/or with the senior design. The key is to be patient, but persistent.

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Acknowledgments

This research has been supported by the National Science Foundation Grants 1,447,395 and 1,632,408