

2006-01-0517 Challenge X Mentoring: A Perspective on an Extraordinary Learning Experience

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ABSTRACT

General Motors (GM), the Department of Energy (DOE), and other U.S. government and industry leaders have joined together to challenge students from 17 North American universities to apply advanced technologies toward the energy and environmental issues facing the automotive industry through the “Challenge X: Crossover to Sustainable Mobility” competition. This competition departs from previous ones by requiring students to use the same product development process that is used by the industry, which emphasizes the use of models. Through the words of students and mentors, this paper reports on some key lessons the students learned in the first year of the competition and the extraordinary insights mentors and university teams gained in the process.

Index Terms – Automotive Product Development Process, Challenge X, Learning Experience, Model-Based Design

INTRODUCTION

“Challenge X: Crossover to Sustainable Mobility” is a ground-breaking, three-year competition sponsored by General Motors (GM), the Department of Energy (DOE), and other U.S. government and industry leaders[1]. This competition challenges students at 17 universities in North America to conceptualize and develop next-generation vehicles that will minimize energy consumption and reduce tailpipe emissions. Challenge X provides engineering students with an opportunity to participate in hands-on research and development using leading-edge automotive propulsion technologies, fuels, materials, and emissions-control technologies. At the same time, students involved in the Challenge X program experience a unique opportunity to use the GM product development process to design and develop these future vehicles. In this way, Challenge X offers an opportunity for students to explore cutting-edge engineering careers.

The MathWorks mentors are six individuals who have a combined experience of 28 years in the engineering software field, including careers with OEMs, sponsors, and academia. With a combined tenure at The MathWorks of X years, ranging individually from 2 to 7 years, the mentors were selected based on a combination of interest in the Challenge X project, their backgrounds, and their individual skill set. The six mentors are each assigned two to three teams and respond to questions from each team, while relying on the collective knowledge within the six-member mentor group. The goal is for each mentor’s expertise to become a source of reference for the entire host of 17 teams.

The mentors help students create a fuel-efficient vehicle using MATLAB® and Simulink® [2]. These students are learning in a variety of modes: intensive individual online training, rigorous classes at The MathWorks, remote phone and e-mail coaching, and in-person work with university advisors and mentors. However, the most important learning experience is the collaborative work of the students themselves. This paper focuses on the learning aspects as they relate to using Model-Based Design.

Model-Based Design

In a traditional product development approach, engineering teams observe strict boundaries between design activities and communicate by passing design documents back and forth. This approach has several drawbacks, such as difficulty in keeping the documents synchronized with the design’s current state, errors associated with recording and understanding the design functionality in document form, and the need to code the application manually. When documents are used as deliverables and shared electronically, engineers often duplicate efforts, and it is difficult to trace the source of errors along a paper trail.

Engineering teams in the automotive, aerospace, and other industries have turned to Model-Based Design to address these problems [3]. Using Model-Based Design, designers and engineers are able to address increasing product complexity, more stringent performance requirements, and shorter product development cycles. Using models in the early design stages, engineers can create executable specifications that enable them to immediately validate and verify specifications against the requirements. This approach allows engineers to detect errors earlier, when they are easier and less costly to fix.

Further along in the design process, engineering teams use models to communicate with other teams across different corporations. This allows for collaboration and communication between teams, throughout each stage of the development process. Teams can extend initial design models incrementally to include increasing implementation detail. Model-Based Design lets engineers experiment with different design alternatives, even in very early conceptual design stages, while having an executable specification. Later, as the project proceeds, Model-Based Design enables engineers to add detailed implementation effects to the same model. This method contrasts with the document-centered approach. The latter option generates new models of the same system under design from the previous stage's specifications.

Building on the success of Model-Based Design, model transformation allows engineers to generate different representations of the same system. This minimizes the effort of moving from one design stage to another. In particular, using automatic code generation technology and hardware-in-the-loop testing alleviates errors introduced during manual implementation and realization tasks. Model transformation significantly shortens the path to product delivery by generating code for testing, calibration, and production.

Challenge X Teams' Learning Experience

The student teams in the Challenge X program experienced Model-Based Design first-hand during the program's first year. Not only did the students receive exposure to a real-world, state-of-the-art vehicle product development process at GM, they also learned the following real-world benefits of these processes.

Using Models to Experiment with Different Design Alternatives

A key goal of the competition is determining an optimal powertrain configuration. This involves iterating across many different automotive propulsion, fuel, materials,

and emissions-control technologies. It is clearly not feasible to evaluate the various possibilities using hardware. One team experimented using a planetary gear train arrangement and was trying to decide on the optimal configuration to connect the components to the planetary gear train. To determine an optimal configuration quickly, the team rapidly built a model of the various configurations using SimDriveline, a library of driveline components provided by The MathWorks.

Using the Model in Multiple Design Stages

Once the students developed a model to evaluate their ideas for a powertrain configuration, they used that model to develop a vehicle-level control strategy to optimize design performance. The ability to develop and verify a control algorithm with the same model enabled them to meet the competition goals and deadlines.

Using Models to Detect Errors Earlier When the Cost to Fix These Errors is Less

A significant benefit of using Model-Based Design is to recognize costly errors early in the process. A traditional development process involves realizing the design in hardware to determine whether it meets the program requirements. For example, one of the Challenge X teams decided to use a fuel cell-based vehicle architecture. The supplier of the fuel cell stacks provided two different fuel cell sizes. By performing simulations using tools from The MathWorks, the students determined that neither size met the competition's goals. The simulation results were presented to the fuel cell manufacturer and were instrumental in convincing the manufacturer to provide a new fuel cell. Using the models avoided costly hardware design iterations and led the team to select the optimal architecture.

Using Models to Enhance Collaboration and Communication with Partners and Suppliers

In the above example, not only did the team avoid costly and expensive hardware prototyping during the initial design, they also improved their communication and collaboration with the fuel cell manufacturer by presenting models that demonstrated the effect of the fuel cell size on vehicle performance.

Insights on the Learning Experience

The following responses include input from faculty advisors of university teams and student team members. While names and affiliations have been kept confidential, quotes and summaries of responses have been identified as originating from professors (P) or students (S).

1) *A goal of the Challenge X program is to prepare students for industry roles. How did your team's*

interaction with The MathWorks mentor, when working with Model-Based Design, support this goal?

Students are exposed to the model-based approach on a large-scale project. Without Challenge X and without Model-Based Design, our students would only be exposed to small projects for which Model-Based Design is not needed. (P)

The support provided by The MathWorks mentor proved to be pivotal in helping students working on the design solve their problems in a way that challenged and motivated them. Instead of spelling out cookie-cutter solutions, the mentors suggested areas that students should explore, and let them solve their own problems. Our mentor's comments on our Design of Experiments approach were that using the Optimization Toolbox with MATLAB might lead to a more effective use of computer/people resources. Effective use of people and effective use of limited computing resources is crucial in an industrial environment. (S)

While face-to-face interaction with the mentor was too late to significantly affect the manner in which the team pursued their design, the feedback on their approach was invaluable. In addition, MathWorks onsite training was extremely useful, enabling us a good overview of the software tools that we may find useful in our future endeavors. (S)

(2) What could we mentors do to better prepare students for competition?

I would like to see more onsite visits from our mentor so we can really pick his brain and get more one-on-one time. Starting slow would be better than a full-fledged intensive session where we received too much information too quickly to apply. (P)

The online workshops were great for our team. If we had met earlier in the term, I would have used them as a class assignment for all students. (P)

Stay in the loop: Get in cahoots with all other mentors for a particular team and force the team to feed updates to the mentors every two weeks. This will keep the mentors involved, and will help mentors to guide their teams toward more productive approaches. Updates can be as short as one or two pages. (S)

Provide training materials to the students who have attended onsite training, so that they may provide similar training to the students who did not attend. We generally host MATLAB/Simulink training three times a year - once a semester - open to anyone in the school. We do this partially in order to recruit members, partially to make current members more useful to the team, and partially because we believe it's an important piece of software that all engineering students should know and that is currently not taught. (P)

To prepare students specifically for first year, there should have been a review of the material that would be presented. Unfortunately, I was unable to attend any of the other teams' technical presentations, but perhaps an in-depth review of their presentation material (by their mentors), would have helped. Waterloo spent 4-5 hours with our GM mentor the night before the technical and controls presentations in order to ensure that not only would we be able to aptly handle any questions that judges threw at us, but that the presentations were clear and concise, and used jargon and lingo the judges were familiar with. Our mentor also helped us understand what the judges were looking for – are they most interested in safety, failure mitigation, or performance? Did they want us to describe our design process? (S)

Given more time, I would have liked to see the MathWorks mentor sit down with us and discuss how we can exhaustively examine all sides to our design – how can we optimize it? Is it the best possible design? By giving us the tools to conclusively prove that we had an optimum design (within our constraints), our mentor allowed us to provide data to the judges that convinced them we knew the intricacies of our design intimately. (S)

(3) One mentor said "Students in some cases are able to do things "as well or better than those at an OEM." If this is the case, what should we in industry be learning from the success of student teams' learning and production processes?

Perhaps industry is unwilling to use Model-Based Design while some universities jumped into it because it is cool. I recommend teaching Model-Based Design in school, and industry will eventually pick it up because students know how to do it and see the value. (P)

The mentor may have been referring to the way that students are able to operate outside of the constraints of corporate culture. While the corporate development team culture and company standards are important and unavoidable, it sometimes serves to narrow the ability of engineers to innovate and cultivate new ideas. In the same way, the multidisciplinary and free methods that Challenge X allows students to explore provide fresh perspective and leads to unprecedented results. (S)

(4) Why would a company want to associate with a university?

If students learn and use your tools, they will continue to use your tools when they enter industry. Some companies know this and donate their software to schools, while other companies make schools pay for software. (P)

Universities offer a non-commercial approach. The focus is on research and teaching, not at producing product. Using a university as a method for exploring new

techniques/ideas/products that may require significant development energy/cost at the company could be performed significantly cheaper at a university, with newer, fresher approaches. (S)

Universities grow engineers. There is no better place to attempt to mold engineers into useful workers than at this stage. It is the optimum time to introduce technical tools into the young engineer's arsenal. By doing this, you are removing the cost of training from the future employer of this student, making your tool more valuable. (S)

It can be useful to understand how new generations of students are using a company's technical tools. Perhaps new, innovative uses are being introduced. Perhaps new functionality is introduced. Perhaps those tools are being obsolete-ed by new design methods. Tools that are as open and as versatile as Simulink are particularly susceptible to being modified to meet student's needs. (S)

Sometimes companies (especially large companies) are stuck in the rut of legacy technology/practices. The best example is the use of legacy software in vehicle controllers. While we can apply a fully integrated approach to our modeling and software development process using modern tools, a big automotive manufacturer can be stuck, for whatever reason, using code that was written 20 years ago. In these types of situations, small, dynamic teams can completely outperform a large, lumbering corporate machine. (S)

One thing our mentor was surprised at was the extent to which we motivated our entire team to participate in vehicle modeling and simulation. This was done in order to reduce time spent by one or two people, but also so that we had a broad base of people who understood the concepts of vehicle design, modeling, and, most importantly, the rationale behind our technical decisions. Sometimes the learning process is more important than the efficiency of the design process. This is something that industry could learn from academia. (S)

(5) The model of mentors/students supplies good insights into how students learn and allows us to apply that to our own training/curriculum for academia and industry classes.

I think we need all levels of training. One-on-one training is best; Web-based training is worst. However, I believe that the bandwidth issue is important. We really need little bits of training distributed over a long time. Your tools are so large that we cannot absorb everything in short training courses. How about having a monthly live Web/conference call based seminar on new tools that we can use. It should be hands on so that we can use the features. (P)

The best learning is always the lessons learned from trial, and particularly error. This being said, the opportunity that our team took to train its members in MATLAB and Simulink products was also an ideal learning experience - teaching something is an excellent way to learn it. (S)

(6) What characteristics of your Challenge X student teams would you like to see mirrored campus-wide or in industry to continue the passion we often see in teams but not necessarily in industry?

I don't think what we learned in Challenge X can be applied to standard courses because in Challenge X we have a huge project where we have to work together on a long project. This can only be simulated in the classroom and students can sense a fake setup. As far as industry lack of enthusiasm, I would say that when I see something cool, I have the freedom to pursue it. SimDriveline was cool so we jumped on it and decided to use it. I doubt that we would have that freedom in industry. (P)

A solution to this problem would be to establish inter-industry competitions of this nature (a solar car race already exists) that reunites engineers with their creations. The problem with industry is that the market forces, the ad campaign, the fickle consumer can all destroy what was a great technology. In Challenge X, none of these things except for the product matter, which is what motivates engineers to put forth such great efforts. (S)

(7) How do students learn?

Some students needed guidance and someone to push them into using the tools. The excitement around Model-Based Design for students was not initially as great as it was for faculty. The faculty advisors immediately saw the power in the tools, while students may have seen the tools as another new thing to be learned in school. Students don't always immediately see the power of simulation. (P)

No step-by-step guidance needed. I think every member on the team knew coming in that modeling was and should be an important way to understand our vehicle. The top technical people trained themselves (with books and papers and the Internet) how to use Simulink and how to build vehicle models. By the time of the first MathWorks training session in Boston, we had a simple vehicle model up and running. What we really needed at that stage was a lesson in the simulation tools and a lesson in how we should use the model in the most effective way (which was missing). (S)

(8) What was the essence of your team's productivity?

The attitude of our team is to do what is needed when it is needed. Most students are willing to do what it takes

to get a job done. The real problem is that because ours is largely an undergraduate team, students don't have enough experience to know how to complete a job. Thus, a lot of interaction is needed between students, advisors, and mentors. (P)

The externally enforced deadlines drove the design. While the vehicle's macroscopic details were discussed in a group setting weeks before decisions needed to be made, almost all of the implementation details were decided mere hours before the reports were due. (S)

CONCLUSION

Challenge X is a unique example of how industry and academia can work together toward a common goal. This goal involves many intermediate steps where industry and the school objectives blend together to the benefit of both. Industry is exposed to the school environment, and students get a glimpse of what industry expects from students. This interaction produces learning opportunities for all involved.

The students have learned, and are continuing to learn, the benefits of using models in the vehicle design process. They experienced the real-world concerns facing automotive manufacturers and engineers, and as a result, are better prepared for engineering careers. In the next phase of the competition, they will leverage these models further by directly implementing their

control models on embedded processors to meet or exceed the goals of competition in a timely manner, and to get their designs right the first time.

Going forward, The MathWorks will implement ideas suggested by Challenge X teams to improve upon mentoring and the team learning process in year two of the competition.

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