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GT MENTOR: A High School Education Program in Systems Engineering and Additive Manufacturing

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Abstract

The Defense Advanced Research Projects Agency (DARPA) is sponsoring the MENTOR program as the outreach part of its Adaptive Vehicle Make suite of programs. Georgia Tech has been awarded a contract to involve up to 1000 high schools after 4 years in a series of prize challenges. A web-based collaborative design-manufacturing infrastructure will be developed that integrates CAD, CAE, design-for-manufacturing, and CAM software tools with a network of 3D printers and other manufacturing resources. In distributed teams, students will design, fabricate, and construct electro-mechanical systems (e.g., ground vehicle robots) to perform complex tasks. Many parts they design will be fabricated on 3D printers that are located in high schools or nearby sites. A project objective is to have students learn about collaborative design, advanced manufacturing, and new product development practices and to become excited about pursuing technology-based careers.

1 DARPA Manufacturing Experimentation and Outreach (MENTOR)

The DARPA Manufacturing Experimentation and Outreach (MENTOR) BAA was issued October 18, 2010 by the Tactical Technology Office (TTO). The total amount of money to be awarded was $10.0 million with multiple awards anticipated. The MENTOR effort is part of the Adaptive Vehicle Make (AVM) program portfolio and "…is aimed at engaging high school students in a series of collaborative distributed manufacturing and design experiments. The overarching objective of MENTOR was to develop and motivate a next generation cadre of system designers and manufacturing innovators, and to ensure that high school-age youths are exposed to the principles of modern prize-based design and foundry-style digital manufacturing" (quotes are taken from the BAA).

The end vision for MENTOR was the "…development of user-friendly, open-source tools to enable the utilization of conventional social network media (e.g., Facebook apps) for the purpose of collaborative distributed design and manufacturing across hundreds of sites and thousands of users." This capability will be accompanied by the "deployment of an inexpensive, heterogeneous set of digitally-programmable manufacturing equipment (e.g., 3D printers for various materials) to 1,000 high schools globally." Prize-based design and manufacturing challenges would then "enable clusters of schools to team and compete against one another in the development of cyber-electro-mechanical systems of moderate complexity such as go carts, mobile robots, small unmanned aircraft, etc."

Three teams were awarded contracts for the MENTOR program in Fall 2011, including one from Georgia Tech. Each is a 1-year contract, with options for succeeding years. The Georgia Tech team is hopeful of being renewed to continue working on the project.

2 The Georgia Tech Approach

Georgia Tech being the U.S. largest producer of engineers has the resources and mechanisms in place to meet the vision and satisfy the objectives that DARPA seeks in its MENTOR Program. Faculty from three schools in the College of Engineering: Aerospace Engineering (AE), Electrical & Computer Engineering (ECE), and Mechanical Engineering (ME), who have had extensive design & manufacturing and outreach interest and experience, teamed together, along with other key Georgia Tech personnel to provide the necessary leadership. An illustration of the GT MENTOR organizational structure and element leads is provided in Figure 1.

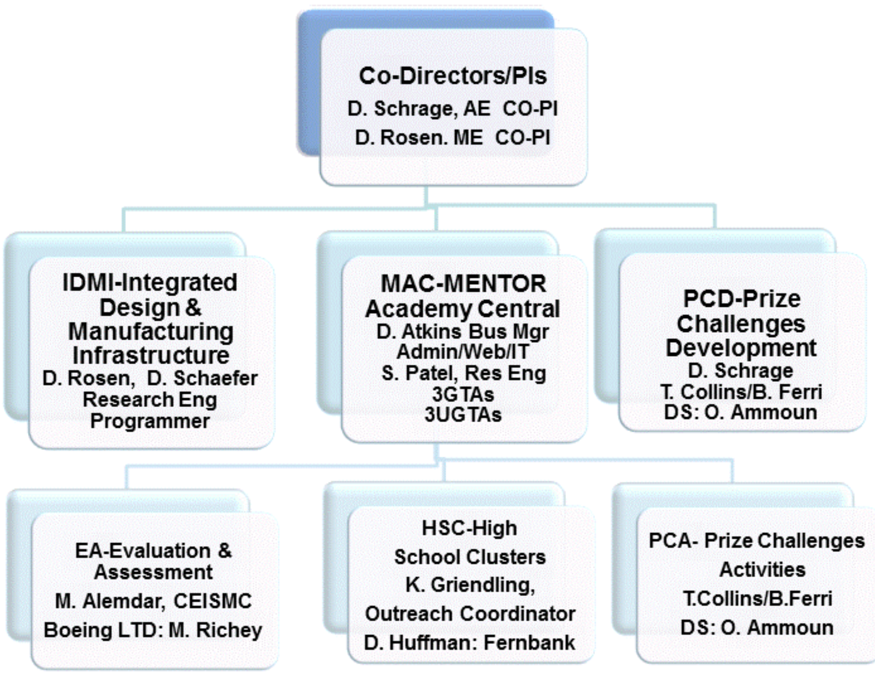

Figure 1. GT MENTOR Organizational Structural Elements.

Dr. Dan Schrage, Professor and Director of the Integrated Product Lifecycle Engineering (IPLE) Laboratory in the School of AE, and Dr. David Rosen, Professor and Director of the Rapid Prototyping and Manufacturing Institute (RPMI) in the School of ME, serve as the Co-Directors /Co-Principal Investigators (Co-PIs) for the GT MENTOR Program. Dr. Rosen, along with Professor Dirk Schaefer, School of ME, lead the Integrated Design & Manufacturing Infrastructure (IDMI) element. Mr. Dale Atkins, Senior Research Engineer, and Mr. Srujal Patel, Research Engineer, in the School of AE lead the MENTOR Academy Central (MAC) element which overseas the day-to-day activities of MENTOR, as well as planning and interfacing its self-sustainment. Dr. Schrage, along with Dr. Bonnie Ferri, Professor and Associate Chair of the School of ECE, and Dr. Tom Collins, a Senior Research in the Georgia Tech Research Institute (GTRI), along with a joint appointment in the School of AE, conduct and oversee the Prize Challenge Development (PCD) and the Prize Challenge Activities (PCA) elements. Joining them in this capacity is Mr. Olivier Ammoun, a Senior Research Manager with Dassault

Systemes. Dassault Systemes (DS) provided to GT MENTOR several of the capabilities that the DARPA MENTOR Program sought. First, they are the world's leader in introducing modern Product Lifecycle Management (PLM) knowledge for outreach education activities. The DS PLM Discover middleware architecture was specifically developed for education outreach activities to illustrate and implement how CAD, CAE, and CAM can be applied for cyber-electro-mechanical systems of moderate complexity, as specifically identified in the DARPA MENTOR BAA. The DS PLM Discover targets high school and undergraduate non-expert curricula as illustrated in Figure 2. Being web-based it strongly supports the collaborative national and international environment sought by DARPA to engage 1,000 high schools worldwide within four years.

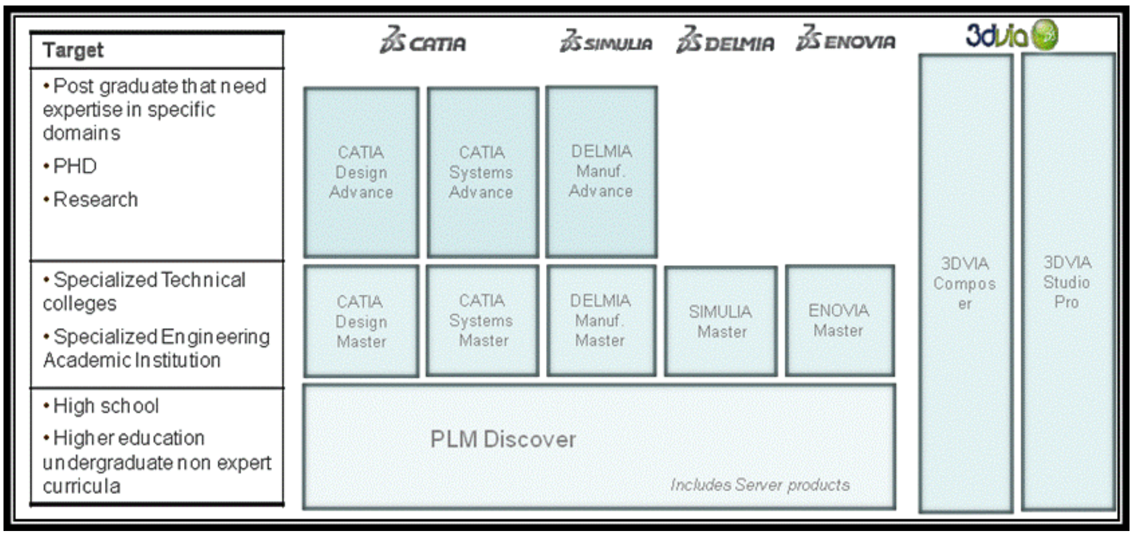

Figure 2. Specific Educational Targets for DS PLM Discover.

The fact that DS already supports in France an educational prize-based competition with more than 1,000 high schools participants from around the world, The Formula One Race Car Competition, greatly lowers the risk for the GT MENTOR Team to reach the DARPA target of 1,000 high schools for its prized-based challenges by the end of four years. CATIA V5 is the basis CAD model used in this competition.

Another key DARPA MENTOR desired capability that DS provides the GT MENTOR Team is user-friendly, open-source tools to enable the utilization of conventional social network media. DS has provided the GT MENTOR Team their See what You mean (SwYm) social network tool, which has already been evaluated in the Georgia Tech 2011 Engineering Summer Camp and will be extensively evaluated in the 2012 Engineering Summer Camp in July 2012. Some sample SwYm results from the 2011 Summer Camp, prior to MENTOR initiation, are provided in Figure 3. It is felt that this evaluation of social networking is innovative and unique. It may also be the first time that social networking has been used and evaluated in a prize-challenge competition simultaneously executed by collaborative team members from two different camps at two different locations.

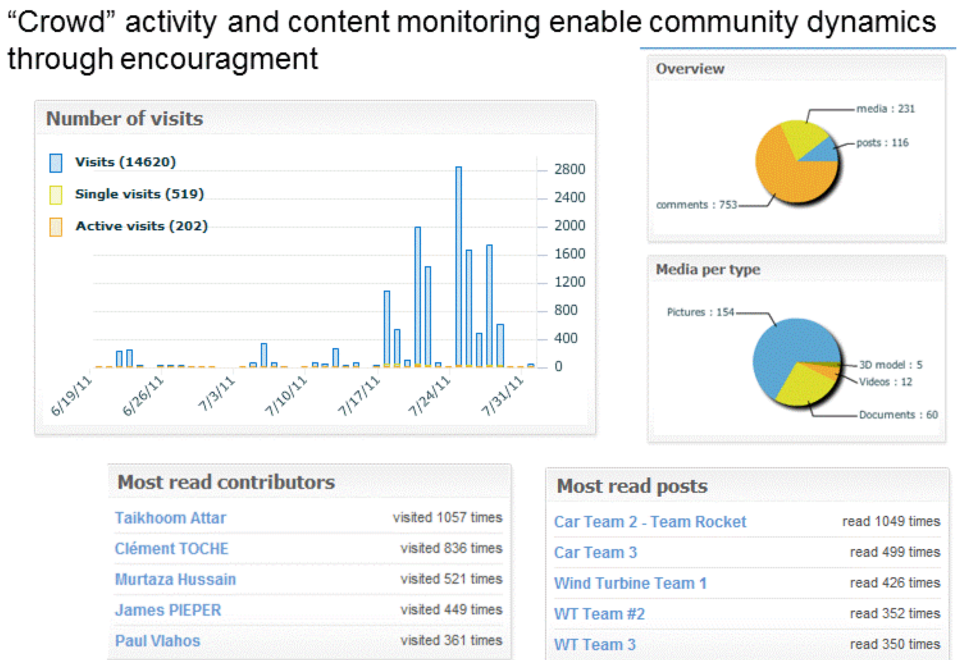

Figure 3. Sample SwYm Results from 2011 Summer Camp.

The Evaluation and Assessment (EA) task in Figure 1 is led by Dr. Meltem Alemdar, Assistant Director for Evaluation in the Gerogia Tech Center for Education Integrating Science, Mathematics, and Computing (CEISMC). Dr. Alemdar’s work to date has been preparing the GT MENTOR Evaluation Plan as well as the Institute Review Board (IRB) Proposal for the GT MENTOR Program, which was approved in July 2012.

Another key element of the GT MENTOR Organizational Structure in Figure 1 is the High School Clusters (HSC). The HSC element is lead by Dr. Kelly Griendling, GT MENTOR Outreach Coordinator. Her responsibilities have been informing high schools about GT MENTOR and identifying the approximately ten development high schools for the first two years of MENTOR development. Dr. Griendling has a large, strong group of GT MENTOR development high schools for the first year, as illustrated in Figure 4. As can been seen 15 development high schools have been identified with five more having expressed interest. With a commitment to exercise the second year of the DARPA MENTOR development phase, it is felt that 40-50 high school clusters could be provided worldwide by the end of the third year. With 8 to 10 high schools per cluster, it is felt that approximately 400 high schools could be involved in the GT MENTOR Program by the end of the third year, greatly exceeding the 100 high schools specified in the DARPA MENTOR BAA. With funding for the year three option, it is strongly felt that the 1000 high schools required by end of the fourth year could easily be obtained. This estimation is strongly supported by the GT MENTOR partner, Dassault Systems, who has successfully supported the Formula One Race Car Competition in France. Also, they have gauged strong interest in the GT MENTOR Program from the numerous high schools they are in contact with.

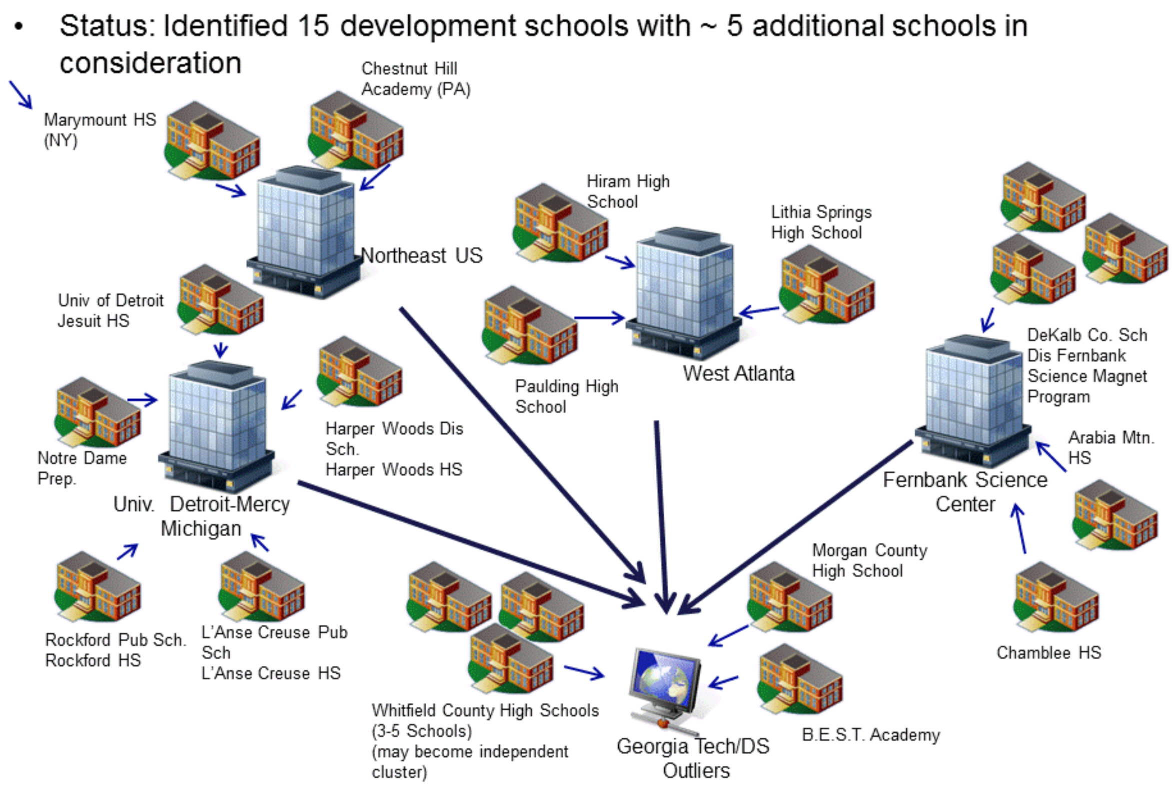

Figure 4. GT MENTOR Development High School Clusters.

The final element identified in the GT MENTOR Organizational Element Chart, Figure 1, is Prize-Based Activities (PCA). As identified, Dr. Tom Collins and Dr. Bonnie Ferri have led two Prized Challenge development efforts supported by the MAC graduate and undergraduate students from the IPLE Laboratory. Dr. Collins led the Wind Turbine Prize Challenge, while Dr. Ferri led the Ground Robot Prize Challenge. Initial Prize Challenge concepts were developed from baseline LEGO NXT kit as illustrated in Figure 5. The Wind Turbine and Ground Robot were evaluated in the 2011 Engineering Summer Camp. While they use the LEGO NXT kits as baselines, the intent is for the high school teams to Co-Create, Design, Build and Operate (CDBO) non-standard parts. For the Wind Turbine this consists of new turbine blades to increase the efficiency for power generation as illustrated on the bottom of Figure 6. For the Ground Robot the CDBO evolution from the Virtual to the Physical for an external non-standard cover is illustrated at the top of Figure 6. These initial Prize Challenges were developed and evaluated during the 2011 Engineering Summer Camp. The 3D printer utilized was from Stratasys. Both Stratasys and 3D Systems are GT MENTOR partners and represent two of the largest 3D printer companies. Thus, GT MENTOR has responded to another of the DARPA MENTOR BAA Objectives: deployment of an inexpensive, heterogeneous set of digitally-programmable manufacturing equipment (e.g., 3D printers for various materials) to 1,000 high schools globally.

The technical approach for the GT MENTOR Program is illustrated in Figure 7. It provides a CDBO framework for collaborative prize challenge development and implementation. It includes the four major life cycle functions for design, development and testing of cyber-electro-mechanical systems. CDBO is a specific implementation of CDIO (Conceive – Design – Implement – Operate), which is a larger framework for undergraduate education aimed at rebalancing engineering science with professional practice. The arrows indicate how the PLM Discover architecture can be used to exchange, store, distribute and re-use the vital product and process data between distributed high school teams for decision-making within their clusters. It also provides the high school students and teachers an understanding of the need for integrated design and manufacturing tradeoffs. In addition, it provides in an easily, understandable way the need for cycle time reduction, a key objective for the DARPA AVM Program, for which MENTOR is supposed to be a microcosm.

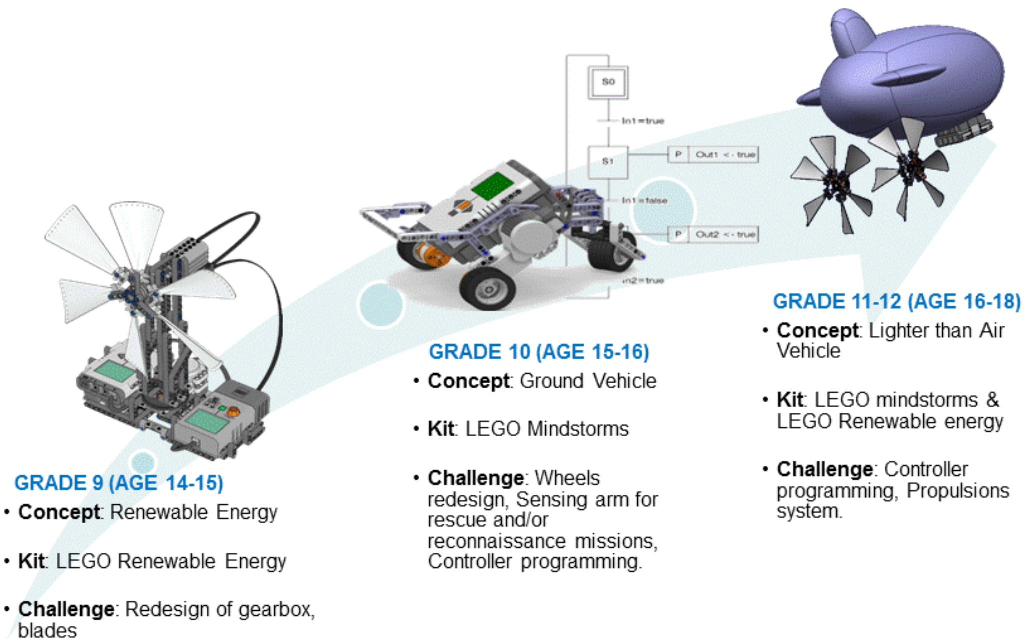

Figure 5. Initial Prize Challenge Development.

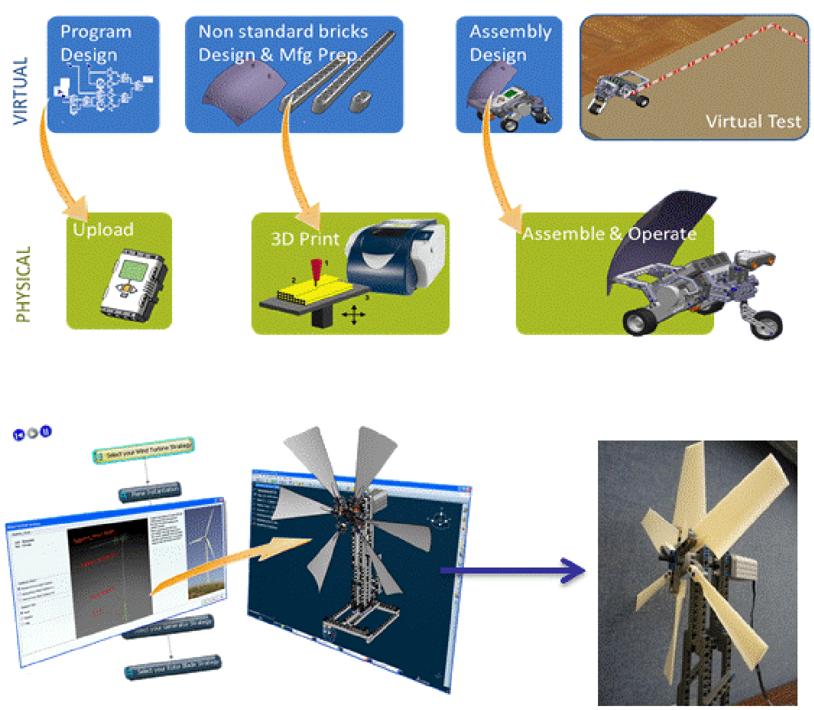

Figure 6. Wind Turbine and Ground Robot Prize Challenges.

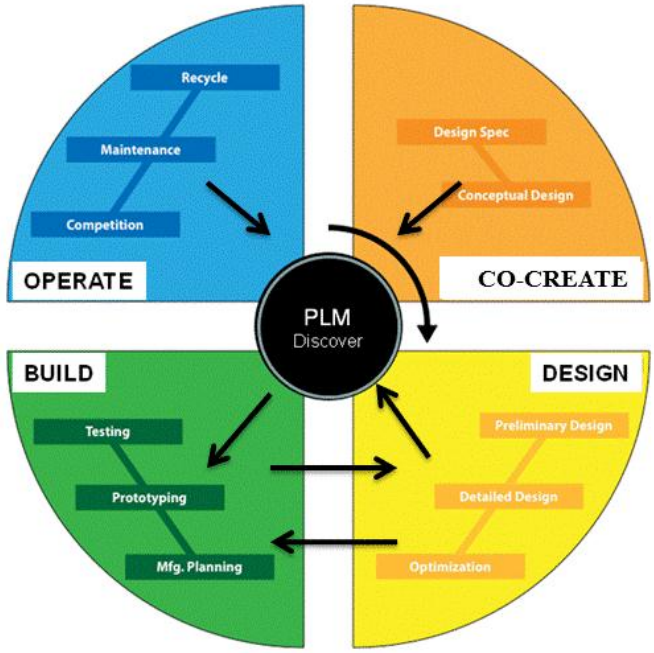

Figure 7. GT MENTOR Technical Approach.

Each summer Dr. Schrage offers a 2 week summer camp on engineering systems design to high school students. Students learn CATIA, collaboration, systems engineering, and 3D printing. Students work in teams of 2-4. During the 2011 Engineering Summer Camp, teams were composed of 2 students at Georgia Tech and 2 more at the University of Detroit-Mercy. Students worked on either the wind turbine or ground vehicle projects. The technical approach illustrated in Figure 7 was initially evaluated for the 2011 summer camp and proved to be quite successful. The 2012 Engineering Summer Camp will be July 9-20, 2012 and will include approximately forty high students and ten high school teachers. Many of the students and teachers will be from the GT MENTOR development high schools. In addition, students from six states and one foreign country have also enrolled for the 2012 Summer Camp, many coming with the desire to host their own summer camps in their regions in 2013.

One of the key MENTOR challenges that the GT MENTOR Team has addressed is sustainment. A necessary ingredient for sustainment to occur is to engage high school teachers in professional education and participation in the summer camps, which will help them become the true mentors. Another is to provide a mechanism that will help them upgrade their high school curriculum. With this in mind, the GT MENTOR Program is partnering with the Southern Region Education Board (SREB), particularly with their Preparation For Tomorrow (PFT) initiative. The SREB activities are focused in 20 states, mostly in the Southeast, but spanning from Texas to Delaware. The PFT initiative is to introduce project-based learning through state focused projects over the next five years. Twelve of the states have agreed to incorporate four project-based learning courses (one per year) into their high school curricula, including Georgia, which selected **advanced manufacturing** as their focus.

The GT MENTOR Program is working with the SREB PFT to include prize-based challenges into the four project-based learning courses. This has caused the GT MENTOR

Program to reconsider its prize challenge progressions from Grades 9-12 grades. For Grade 9, the CDBO approach for new turbine blades, similar to Figures 5 & 6, would be followed. It is felt that use of the LEGO NXT kits is a good start for most prize challenges and project-based learning topics. However, it is also felt that the progression should end up with something that is visible and useful to the school. Thus, the objective for the Wind Turbine is to end up with a small workable wind turbine that could be mounted to the school or a pole of some type and demonstrated power efficiency enhancement. Some restaurants and small businesses already use this approach. Thus, in Grade 10 a small wind turbine would be selected and a CDBO approach to mounting it would be the project. In Grades 11 & 12, the small wind turbine would be installed, operated and tested to determine what energy enhancements can be made.

Similar state focused projects will be identified for ground and aerial robots. A ground robot that could assist the high school janitors in doing their jobs could be another application. An aerial robot that could monitor school security from outside could be another application.

3 Integrated Design-Manufacturing Infrastructure (IDMI)

An integrated design and manufacturing infrastructure has been designed and implemented to fulfill requirements for students to gain access to the collaboration environment and design and manufacturing tools. In this subsection, we provide an overview of the system and describe a variety of its key feature sets that have been implemented.

The innovative approach for this work was to provide an IDMI that supports smooth transitions between design and manufacturing resources in order to accommodate timely design and manufacturing tradeoffs and associated processes. The goal was to enable these design and manufacturing transitions in a highly open and collaborative environment. As a result, the system utilized open-source tools and technologies for the vast majority of its feature sets and focused on tools that enable the seamless integration of collaboration technologies [1].

While investigating the various software tools required for the IDMI implementation, the following criteria were established to guide our evaluations: 1) the code must be open source so that we can modify existing features and/or add new features when needed; 2) the systems must be built on top of ‘standard’ and well-established technologies; for example, we consider systems based on Java programming technologies, PHP, etc to be well-established. 3) the systems must be flexible in terms of deployment and user requirements, utilize common operating systems, and support standard HTTP servers, web browsers, database systems (e.g., MySQL).

The Moodle learning management system was selected to function as the underlying centralized interfacing portal of the IDMI. Moodle is a free web-based application used by educational entities around the world to create online learning systems. Moodle is based on standard technologies such as PHP, HTML, CSS, and AJAX. Moodle can be implemented on top of a traditional LAMP stack, which includes a Linux operating system, Apache web server, MySQL database, and PHP. These LAMP components along with Moodle are open source.

The IDMI has a centralized interfacing server (CIS) that hosts the primary IDMI portal and other IDMI resources such as collaboration tools, middleware services, and cloud file systems, which - taken together - form a small cloud-based design-manufacturing environment [2,3]. Figure 8 illustrates the main landing page for the IDMI portal.

The landing page has a 3-panel design along with a header and footer. The left and right panels are based on a ‘block’ layout design whereby different functionality can be added as block elements that contain features such as site navigation, news, RSS feeds, and calendars. The middle pane serves to illustrate the four main categories of resources provided by the IDMI: Design & Manufacturing resources, Collaboration resources, Learning & Education resources, and Teaching resources. Users gain access to the system by clicking the 'Login' hyperlink located at the top right-hand side of the landing page. Upon successful login, the user will be directed to his/her home page.

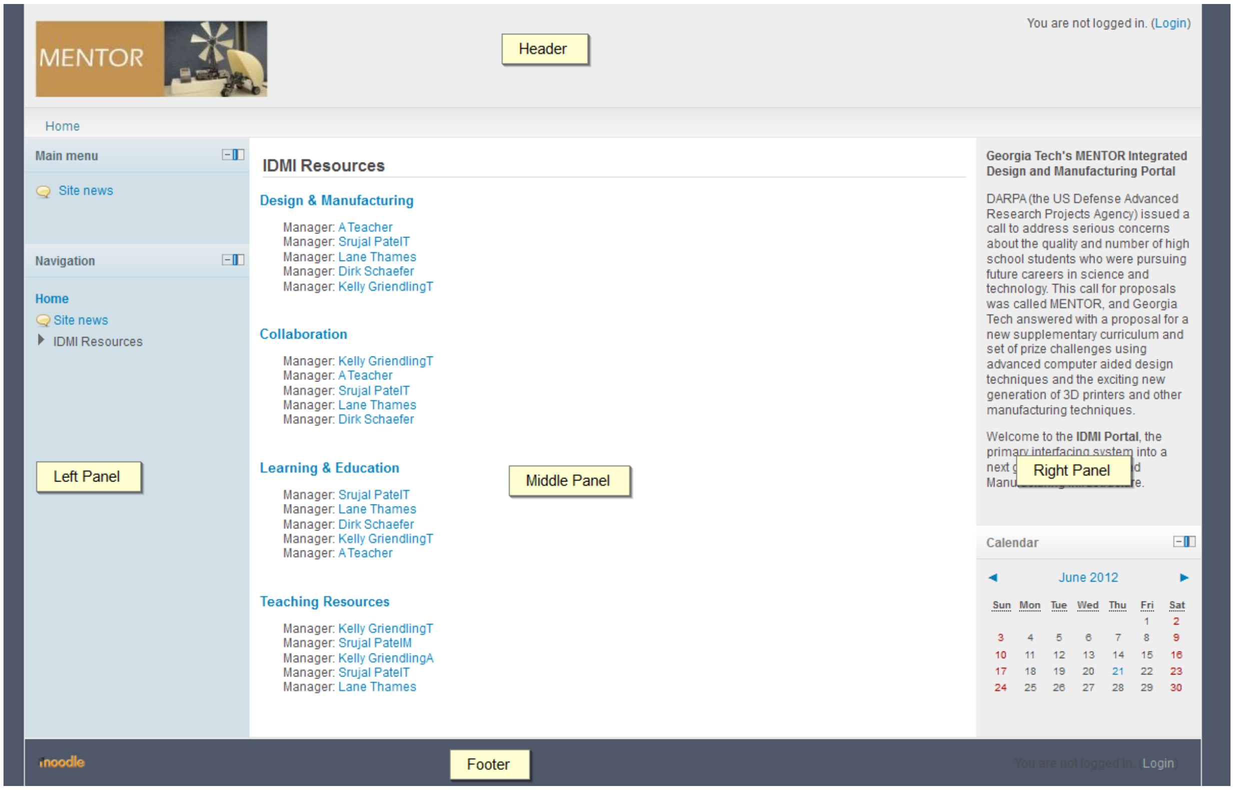

Figure 8: Main IDMI portal landing page.

The system uses role-based access control. The content displayed to the user will depend on the user's role. However, various types of content are displayed independently of role. For example, site administrators will have access to the features provided by the site administration block. Non-administrative users will not see this content. The generic content that all users see, however, are the links to the IDMI's resources defined by the system's portal information architecture along with the file management block, user list block, and site navigation block.

Site administrators access tools for system-wide management via the site administration block. These tools are used to manage system users, IDMI resources, student grades, location settings, language settings, new plugin features, security settings, site appearance, front-page settings, server settings, system event reports, and portal development. After adding a new user to the system, the site administrator assigns one or more roles to the user.

The IDMI portal has been designed to support four types of roles, including: Student, Assistant, Teacher, and Manager. These roles determine read, write, and modify permissions for the content available from within the portal. These roles also determine contextual views available within the site's pages. For example, only managers have access to site administrator tools and these tools are not viewable for non-managers.

In terms of web systems, an information architecture defines the high level categorization and organization of information, resources, and services available to users of a web-based system. For the IDMI, the information architecture is organized around four main categories: Design & Manufacturing resources, Collaboration resources, Learning & Education resources, and Teaching resources. The elements and functionalities of these four categories will be described by the following.

Figure 9 illustrates the IDMI Design & Manufacturing interface. From the design and manufacturing resources interface, users have access to CATIA V6 CAD software provided via a CITRIX web portal interface. The CATIA V6 interface is illustrated by Figures 10 and 11, respectively. From this interface, users also have access to the various additive manufacturing tools that have been incorporated into the IDMI, such as AM-Select and AM-Request, which will be discussed in the next section. Other features available from the Design & Manufacturing interface include collaboration tools such as RSS feed blocks, news and event broadcast blocks, system tools such as log, activity, and participation reports, and generic tools such as forum topic search functionality. Lastly, each top-level category interface has its own dedicated news forum whereby users can collaborate in real time and/or asynchronously.

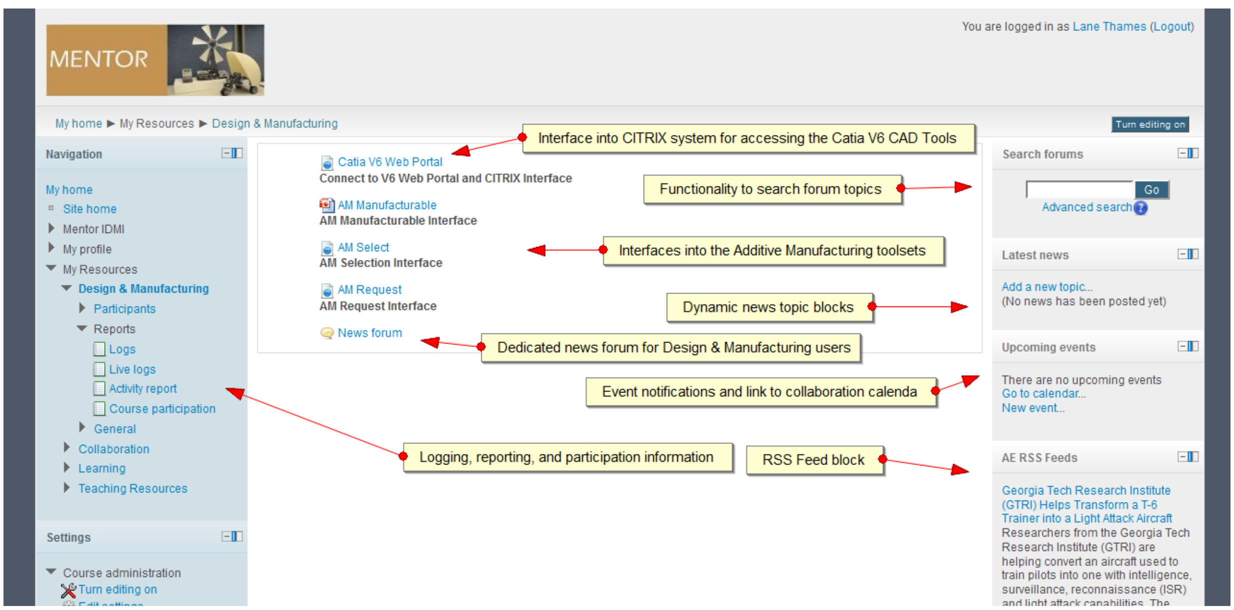

Figure 9: IDMI Design & Manufacturing interface.

Figure 11 illustrates the Collaboration interface of the IDMI. The following technologies have been integrated into the IDMI for both real time and asynchronous collaboration: Chat rooms, Forums, Wikis, Workshops, Blogs, and Agendas. The blogs, forums, and wikis that have been implemented in the IDMI are state of the art and include the capability via web-based WYSIWYG editors to input text and images, which provides for better collaboration during online design processes. Figure 12 illustrates the blogging functionality that has been implemented for the IDMI.

A number of external collaboration systems have been integrated into the IDMI. In particular, the IDMI interfaces with the Wiggio video telecollaboration (VTC) and virtual meeting tool, and a collaborative cloud file system based on Dropbox has been implemented. Figure 13 illustrates the video VTC capabilities of the Wiggio tool. In this scenario, two engineers are collaborating via VTC technology. They both have access to shared files via the cloud file repository of the IDMI and its dropbox functionality. In this scenario, the team is collaborating on a particular design. One team member located in Atlanta, GA has added his STL file to the repository. The other team member located in Savannah, GA is retrieving the file from the cloud repository and is preparing to have the file processed by a 3D printer.

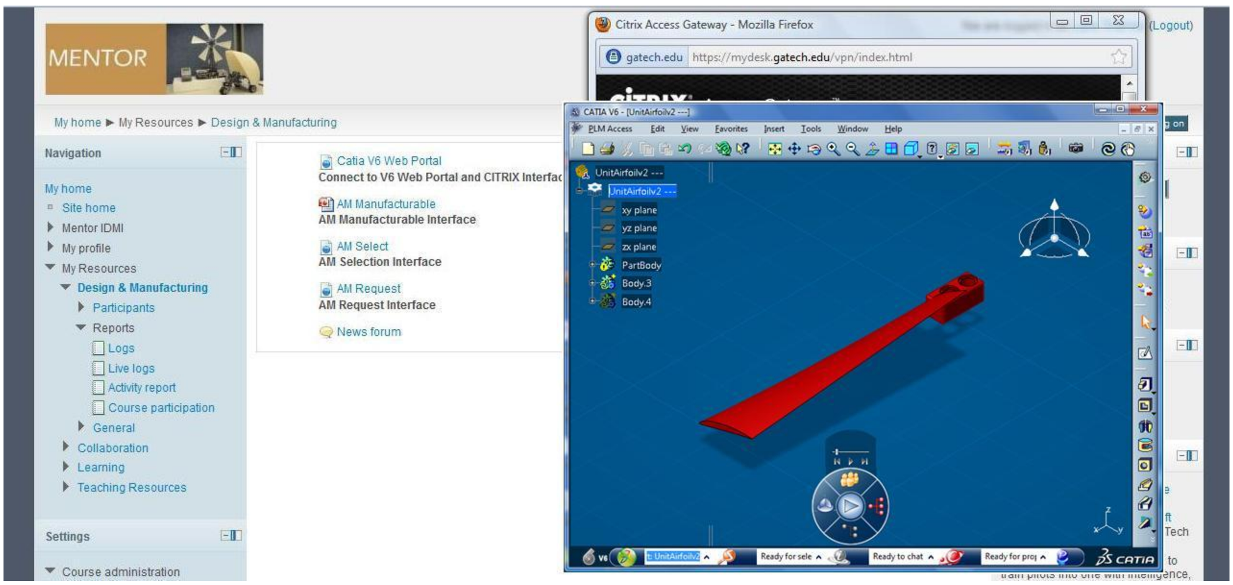

Figure 10: CATIA V6 CAD software accessed by users via the IDMI portal.

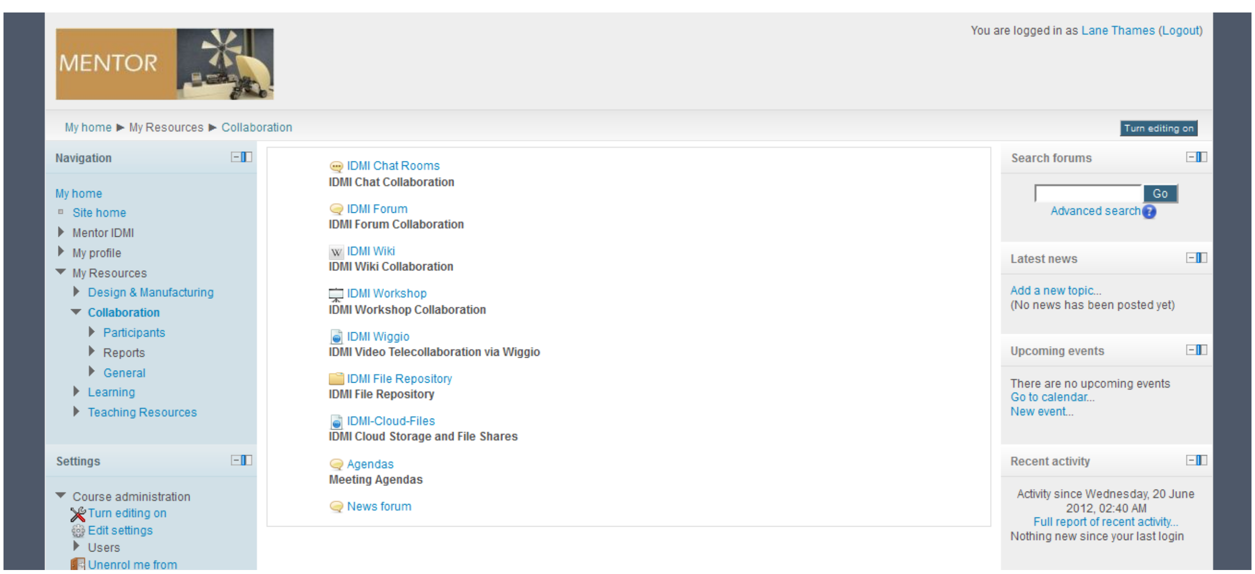

Figure 11: IDMI interface for the primary collaboration tools.

The learning resources interface of the IDMI provides access to students for components such as training materials, course curriculum, and wiki materials. The teaching resources interface of the IDMI provides resources for teachers who use the system. Other than collaboration forums for teachers using the IDMI, the teaching interface also includes tools such as plagiarism detection, course management, grade management, scheduling, agendas, and outcome reporting, just to name a few.

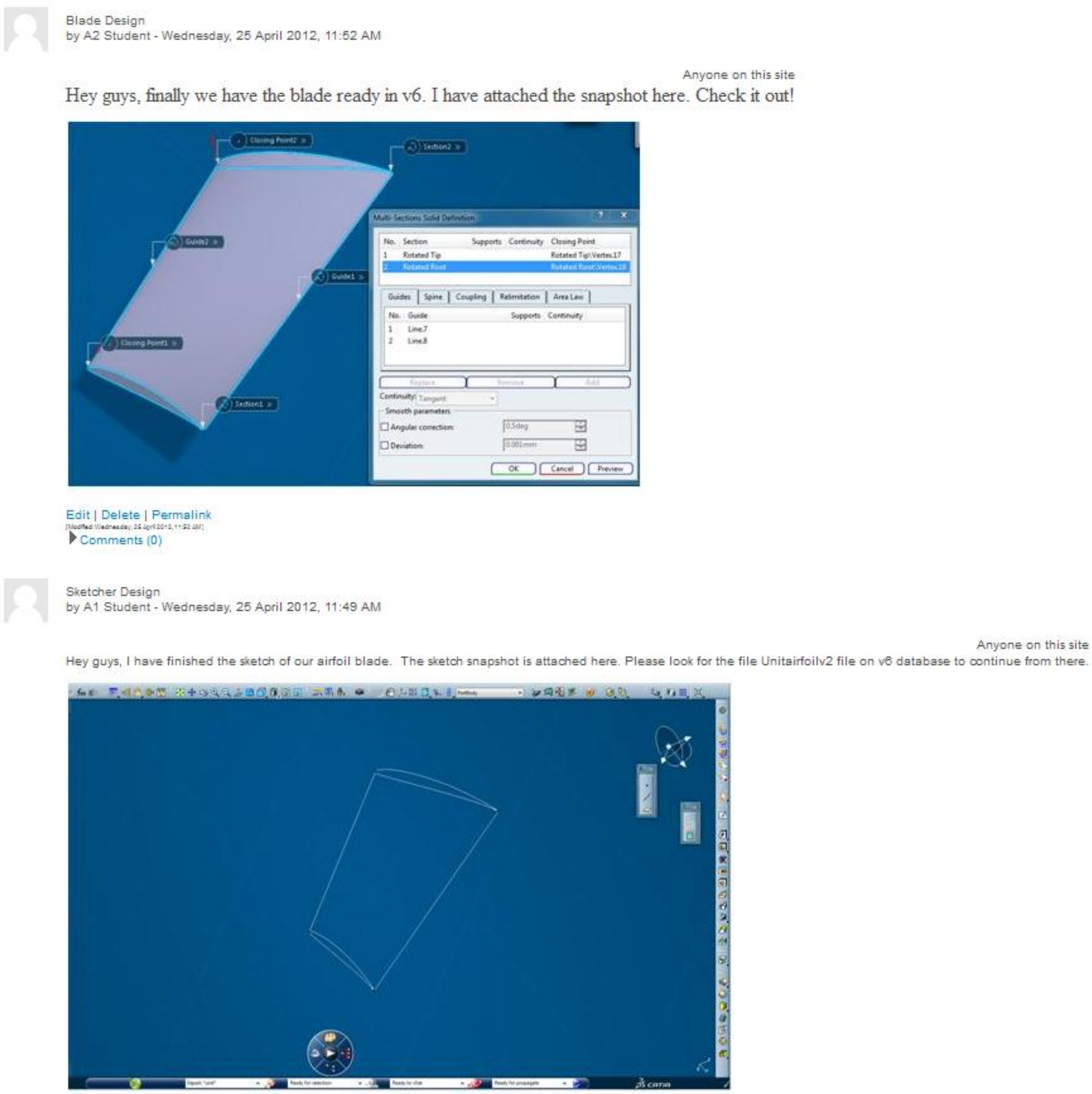

Figure 12: An IDMI Blogging session.

An integrated design and manufacturing infrastructure has been designed and implemented. The innovate approach for this work was to provide an IDMI that supports smooth transitions between design and manufacturing resources in order to accommodate timely design and manufacturing tradeoffs and associated processes. The goal was to enable these design and manufacturing transitions in a highly open and collaborative environment. As a result, the system utilized open-source tools and technologies for the vast majority of its feature sets and focused on tools that enable the seamless integration of collaboration technologies. An overview of the system has been given in this section along with a description of a variety of its key feature sets that have been implemented.

Figure 13: Wiggio integration and functionality within the IDMI.

4 Additive Manufacturing Tools

A set of design-manufacturing software tools were developed to enable students to learn about AM, how to design parts to be fabricated using AM, and how to select appropriate AM processes, machines, and materials, and how to request parts to be fabricated. Alpha versions of the tools, called AM-Select, AM-Request, and AM-Manufacturable, have been integrated into the IDMI framework, as shown in Figure 9, and will be described here. Each application was developed in the C++ language and is web-enabled.

The proposed workflow through the design-to-manufacture tools is shown in Figure 14. Starting in a CAD system, such as CATIA, students create their part designs and save them as STL files. From there, they can learn about the manufacturability characteristics of their designs using the AM-Manufacturable application. This will highlight difficult-to-fabricate features and provide feedback about part size, feature orientation, part orientation in the machine, and other related aspects. Students then have the option of going back to the CAD system to redesign their parts. The AM-Select application reads the part STL file and makes recommendations of processes, machines, and materials, which are passed to the AM-Request application to make the actual request for fabricating the part. Clicking on one of the boxes in Figure 14 causes the software application to launch.

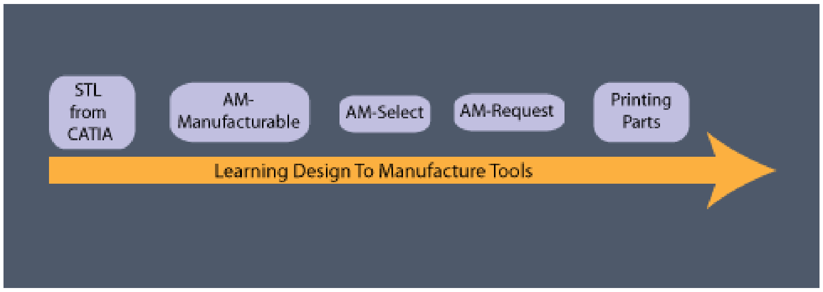

Figure 14: Workflow from CATIA to printed parts.

4.1 AM-Manufacturable

The application AM-Manufacturable reads a part STL file and provides manufacturability feedback to the student about their design. A mock-up of part of the proposed user interface is shown in Figure 15. The interface gets the student thinking about how their part will be fabricated in a 3D printer by asking them about the part's orientation in the machine. By changing the build orientation, AM-Manufacturable will update the "Build Height" and "Support Structure Volume" entries in the interface.

Feedback will be provided on features that are too small to build. Optionally, the user can select a 3D printing process and the database will provide the corresponding smallest feature capability. Or, the user can just enter the feature size with which to evaluate the part. A novel feature size computation algorithm is executed to identify faces that are close to one another. From there, the feature is recognized and its size is determined. Small features are highlighted in the STL part representation and displayed in the CAD system, an example of which is shown in Figure 16, where small features are highlighted in red.

Additional functionality is planned for part size evaluation. If a part is too large to fit into a 3D printer, the user will be notified. Suggestions for how to divide the part into an assembly will be provided.

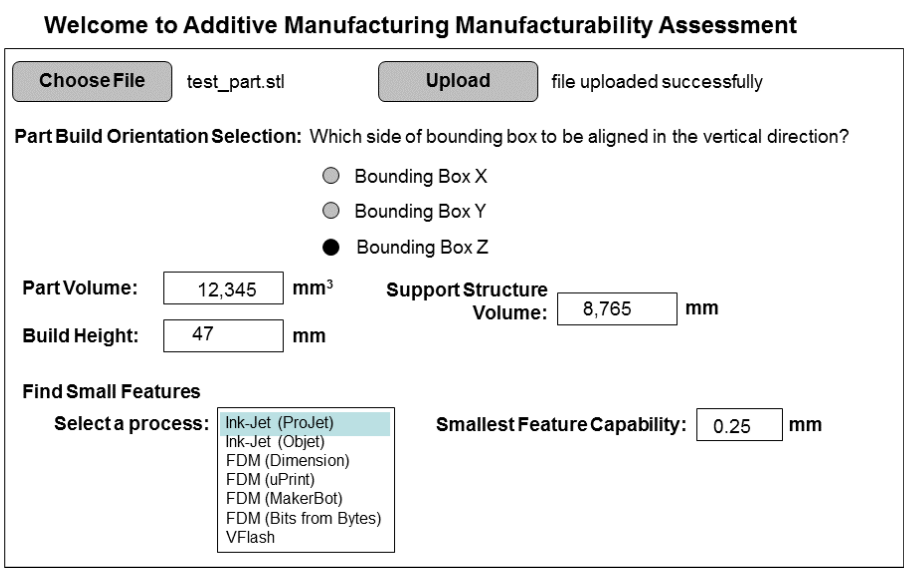

Figure 15: Mock-up of the first AM-Manufacturable interface screen.

4.2 AM-Select

Using the AM-Select application, a user can identify and compare candidate manufacturing processes based on build time and cost estimates that are computed from approximate geometric information about the part. Within each class of manufacturing processes, the user can also identify specific machine types and materials that meet his/her needs. AM-Select can be executed on approximate geometric and size information, specifically the part's bounding box and its estimated volume, which enables process selection at early design stages. Alternatively, AM-Select can be run using the part's STL file so that more precise estimates of build time and cost can be computed.

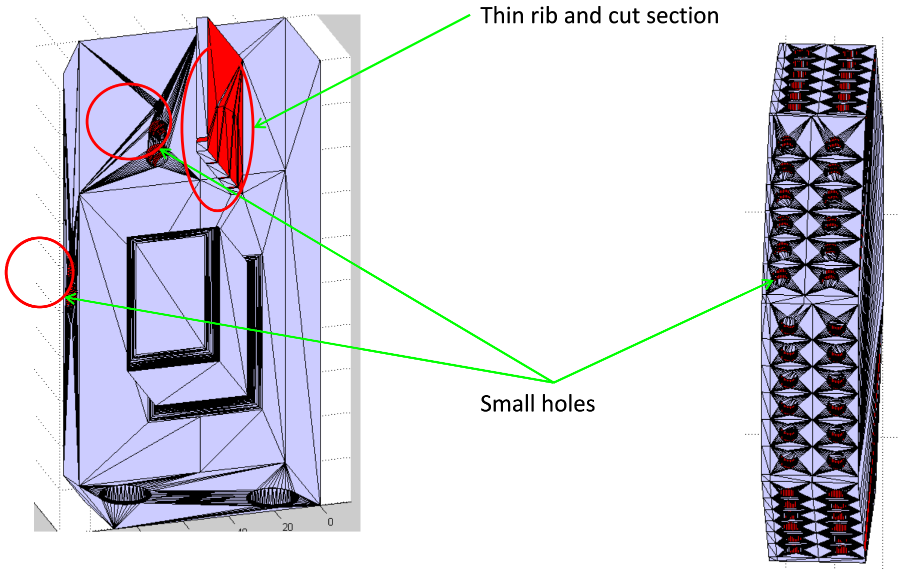

Figure 16: Identified small features in two example parts. Small features are indicated by the red surfaces.

The build time model is based on a generalized parameterization of AM processes that applies to laser-based scanning (Stereolithography, powder bed fusion), filament extrusion (fused-deposition modeling), ink-jet printing, and mask-projection processes. Build time estimates were tested by comparing them to the measured build time of parts in fabricated using Stereolithography, ink-jet printing, and fused deposition modeling processes.

The overall cost is estimated by accumulation of four sub-costs: machine purchase cost (P), machine operation cost (O), material cost (M), and labor cost (L) as shown in Eq.1. Each term is given by a corresponding model. The machine operating cost model involves the estimation of part build time; separate models are used for laser scanning, fused deposition modeling, and ink-jet printing processes, but all share a common structure. More details can be found in reference [4].

$$Overall\ Cost = P + O + M + L \quad (1)$$

A database of processes, machines, and materials was developed for the 3D printers currently commercially available from 3D Systems, Stratasys, and Objet. The database format is straight-forward enabling easy updating when new machines and materials become available.

The database structure was developed as part of the DARPA iFAB project, ensuring its comprehensiveness and robustness.

The AM-Select application has two primary screens to support user interaction. In the first, the user provides either the STL file name or the part's bounding box and estimated volume. Then, the user specifies design specifications on surface finish, geometric accuracy, strength, and stiffness. In all cases, only qualitative values (e.g., low, medium, high) are needed. The first screen is shown in Figure 17.

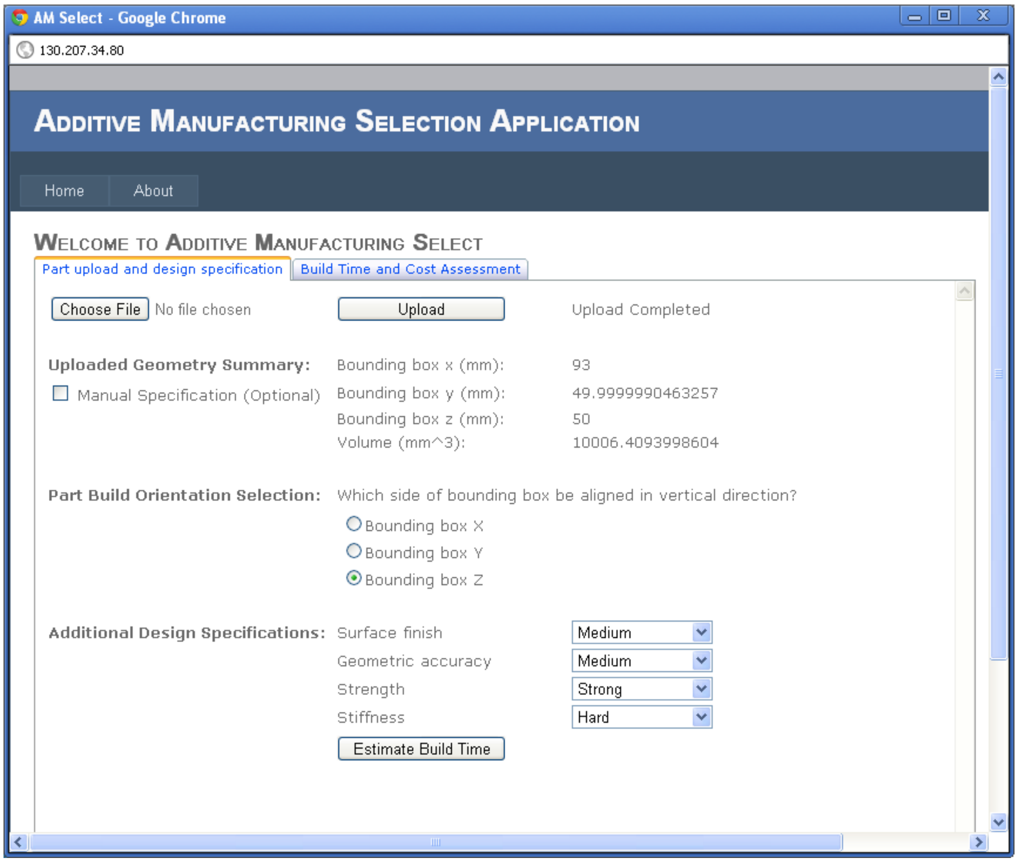

Figure 17: Information input screen for AM-Select.

The second screen shows the results of the build time and cost estimates. Of the machine time and material combinations listed, the user can select one, some, or all listed. When the user hits the "Submit Build?" button, the selected machines and materials are written to a project file in the IDMI that downstream applications can access. An example screen is shown in Figure 18.

4.3 AM-Request

The application AM-Request has a simple purpose: enabling the user to select one machine and material to build his/her part. This selection is for machines that are currently available to the user to use. Upon selection, an email message is sent to the machine operator requesting the part be built. The part STL file is attached to the email. The input to AM-Request is the file that was saved by the AM-Select application, enabling a smooth work-flow from one application to another.

The AM-Request user interface is shown in Figure 19. When the "Retrieve Next Order" button is hit, the AM-Select file is read. A database of available machines, materials, and machine locations is read and compared with the selected machines and materials from AM-Select. At present, this database of available machines was created manually, but in the future, this database will be automatically generated and updated by a tool that scans through the Mentor sites. The user selects one machine, material, and location, then hits the "Send to Printer!" button to send an email message to the selected machine's operator.

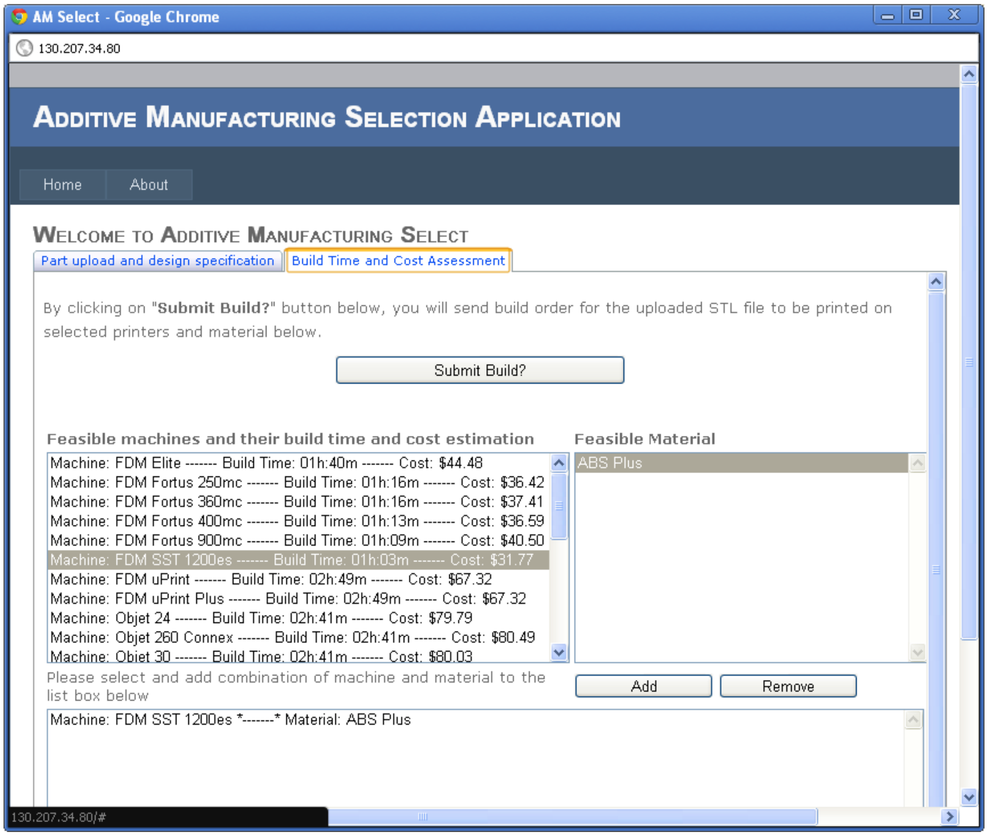

Figure 18: AM-Select results screen.

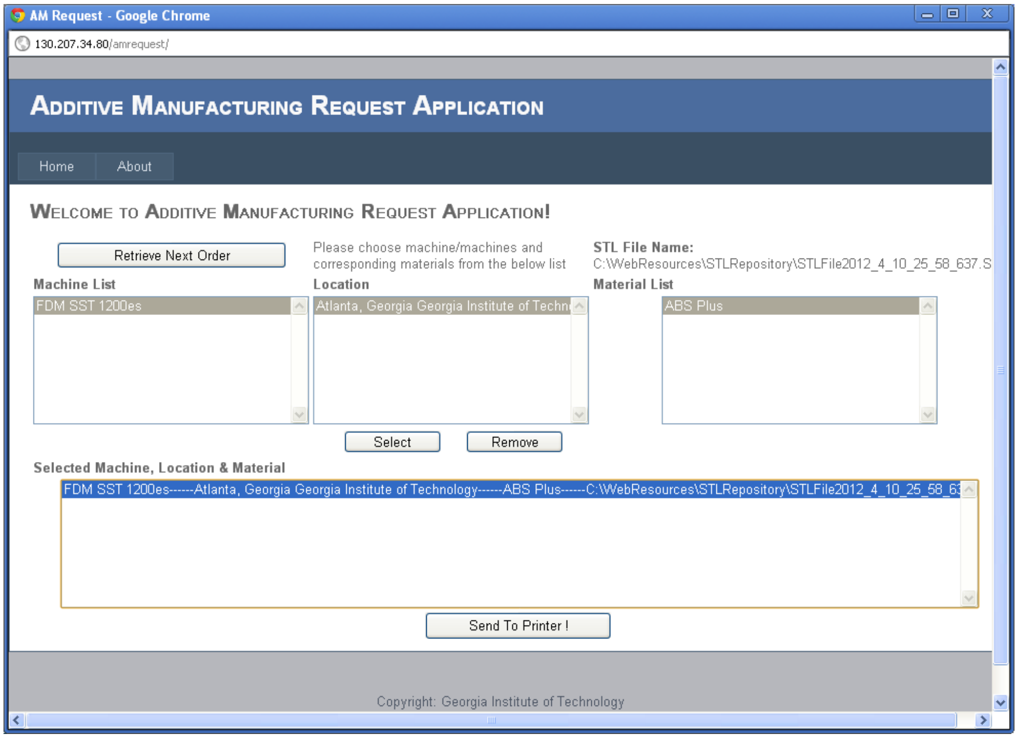

Figure 19: AM-Request user interface.

4.4 IDMI Design-Manufacturing Training Materials

A wide variety of learning materials has been developed and assembled to support the MENTOR project that spans simple CAD, CATIA V6, systems engineering, materials, manufacturing, and technologies related to the current prize challenge. The scope of these materials is shown in Figure 20, which shows the main MENTOR learning navigation page. Clicking on an icon launches a web page showing learning material, brings up a set of more specific icons, or launches a software application. For example, the set of icons shown in Figure 14 is displayed to the user when they select the "Design-To-Manufacture Transition" icon shown along the top row.

As part of the learning materials, a set of tutorials was developed for manufacturing and 3D printing. Manufacturing processes were classified as subtractive, forming, assembly, and additive and descriptions of each were provided. In additive manufacturing, overall concepts and process descriptions were provided, along with descriptions of specific processes, including fused-deposition modeling, stereolithography, laser sintering, and ink-jet printing. Links to external resources, including videos, have been provided.

A materials tutorial was completed that classifies materials into metal, plastics, ceramics, and composites. Descriptions of each class were included. An introduction to material and mechanical properties was incorporated in the materials so that relationships to 3D printing materials and their properties could be made.

Tutorials on the design-to-manufacture software components have been created, specifically for AM-Select and AM-Request. A design for additive manufacturing guidebook will be provided by the end of the project.

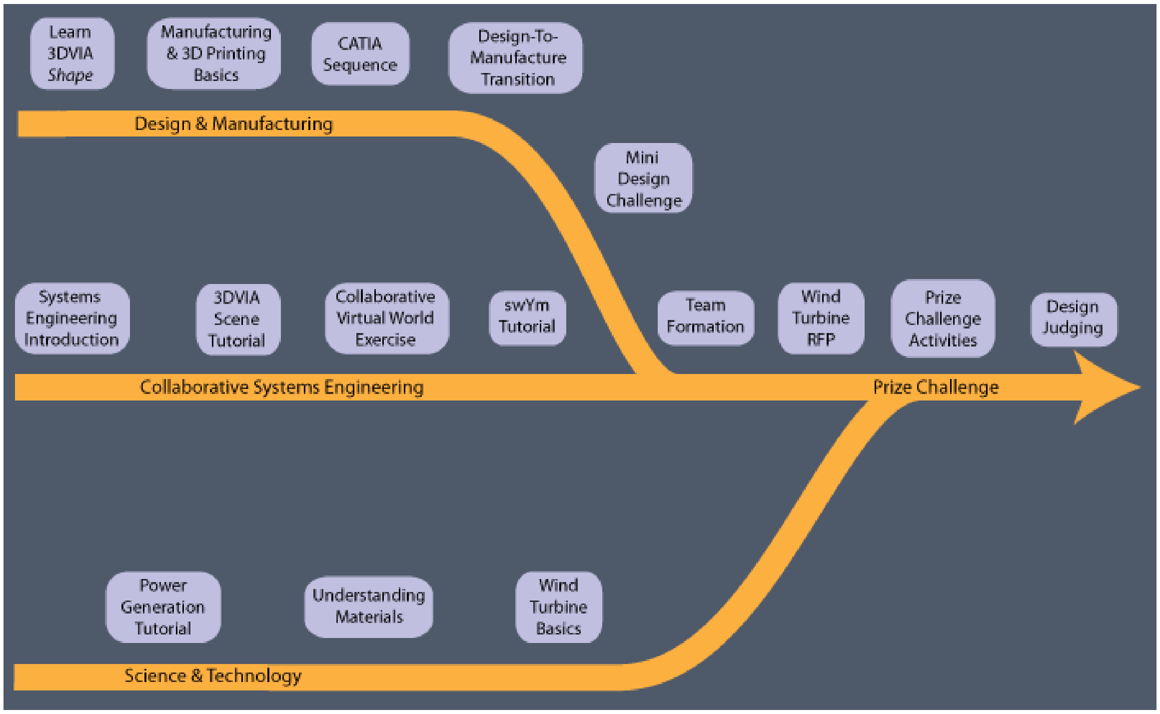

Figure 20: MENTOR learning materials main web page.

5 Closure

The DARPA MENTOR program is the outreach part of its Adaptive Vehicle Make suite of programs. Georgia Tech has proposed a plan to involve up to 1000 high schools after 4 years in a series of prize challenges in which students learn 3D CAD, 3D printing, design for manufacturing, some systems engineering, and distance collaboration and teaming methods. A web-based collaborative design-manufacturing infrastructure was presented was developed that integrates CAD, CAE, design-for-manufacturing, and CAM software tools with a network of 3D printers and other manufacturing resources. In distributed teams, students will design, fabricate, and construct electro-mechanical systems (e.g., ground vehicle robots) to perform complex tasks to satisfy the requirements of prize challenges. Many parts they design will be fabricated on 3D printers that are located in high schools or nearby sites.

At present, 15 high schools are development partner sites and another 40-50 are engaged to become involved during year 2 of the project. By partnering with SREB, the AM and systems engineering content is poised to be incorporated into high school curricula, which could have a tremendous impact in deploying content and involving many high schools in Georgia and across the US in the MENTOR program. Educational materials have been developed and assembled to support the MENTOR program and are available on the web, along with software tools for collaboration, design, design for manufacturing, and 3D printing. Through this project, high school students should become excited about pursuing technology-based careers.

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