Session 1625

Facilitating Distributed Collaborative Product Development in an Undergraduate Curriculum

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Abstract

In the quest to be more competitive, many corporations have embraced Lean Management, Just-In-Time and Total Quality Management coupled with cutting edge Information Technology. Computer Aided Design (CAD) and Computer Aided Engineering (CAE) tools enable engineers to efficiently and quickly realize and simulate concepts virtually, reducing the need for expensive prototyping and testing. Computer Aided Manufacturing (CAM) enables manufacturers to directly utilize information generated by designers to manufacture parts. Product Lifecycle Management (PLM) ties all of these innovations together tracking mountains of data, enabling distributed multidisciplinary teams to share information in real-time over the Internet. In 2002 Georgia Tech and PTC of Needham, MA founded the PLM Center of Excellence at Georgia Tech to explore the concepts of fostering and teaching multidisciplinary Distributed Collaborative Product Development (DCPD) in an academic curriculum. With several pilot programs securely under our belts, we embarked upon a "Grand Experiment" involving students from multiple schools and many disciplines collaborating virtually to design and deliver a product over a two-year period. This paper documents one of the pilot DCPD projects conducted by students and faculty at Georgia Tech and the University of Maryland College Park during the spring semester of 2003 to identify and explore potential issues relating to the "Grand Experiment". We introduce our 2-year capstone DCPD project which began in the fall semester of 2003 with Mechanical Engineering students from Georgia Tech, University of Maryland and University of Illinois Urbana-Champaign collaborating to design an amphibious utility vehicle for the John Deere Corporation. We also outline our plans for involving students from Industrial Design, Manufacturing, Business and other disciplines in the spring semester of 2004 to complete the product development lifecycle complete. We firmly believe that the future of engineering education must involve integrating IT into the classroom to foster multidisciplinary distributed collaborative product development in the undergraduate curriculum and we welcome this opportunity to share our experiences with our colleagues.

I. Introduction

The supply-chain network has become the modern paradigm of the efficient product development environment. Corporations have formed cooperative networks of entities collaborating to produce quality products quickly at low cost. To make such an enterprise system effective, corporate entities have retired "business-as-usual" in favor of lean business practices (i.e. Just-In-Time, Total Quality

Management, etc.) coupled with cutting edge Information Technology. Computer Aided Design (CAD) and Computer Aided Engineering (CAE) tools enable engineers to efficiently and quickly realize and simulate concepts virtually, reducing the need for expensive prototyping and testing. Computer Aided Manufacturing (CAM) enables manufacturers to directly utilize information generated by designers to prepare for and manufacture parts. Product Lifecycle Management (PLM) ties all of these innovations together tracking mountains of data, allowing all parties involved in the lifecycle of a product to share information in real-time over the Internet.

Universities are an integral part of the supply-chain network feeding Industry with students trained in the skills necessary to be productive members of the enterprise. We continuously strive to improve the quality of education we provide to our engineering students by studying industry trends and creating a similar (or superior) environment in Academia. Engineering curricula traditionally emphasize individual learning steeped in gaining theoretical knowledge over applied knowledge, however the days of the individual contributor in industry is gone. Today's work environment demands multidisciplinary teamwork among individuals that may be geographically dispersed. Employees must be concerned and familiar with all aspects of the lifecycle of a product and all operating facets of the corporation. Industry and Academia must collaborate to broaden the experience and education of the engineering student or else Industry will bear the costs of "retraining" them in the field.

In 2002 Georgia Tech and PTC of Needham, MA founded the PLM Center of Excellence at Georgia Tech to develop a paradigm of fostering multidisciplinary product development in an academic curriculum. The crown jewel of this Center is a "Grand Experiment" involving students from multiple schools and many disciplines collaborating virtually to deliver a product design over a two-year period. In this paper we present the a pilot program conducted by students and faculty at Georgia Tech and the University of Maryland College Park during the spring semester of 2003 to identify and explore potential issues relating to the "Grand Experiment." We introduce our 2-year capstone DCPD project which began in the fall semester of 2003 with Mechanical Engineering students from Georgia Tech, University of Maryland and University of Illinois Urbana-Champaign collaborating to design an amphibious utility vehicle for the John Deere Corporation. We also outline our plans for involving students from Industrial Design, Manufacturing, Business and other disciplines in the spring semester of 2004 to complete the product development lifecycle complete. We firmly believe that the future of engineering education must involve integrating IT into the classroom to foster multidisciplinary distributed collaborative product development in the undergraduate curriculum and we welcome this opportunity to share our experiences with our colleagues.

II. Historical Perspective of ME 4041 – Computer Aided Design

At Georgia Tech we have always believed that effective engineering communication involves more than technical writing skills. An engineer must be proficient in describing the intent of a design using both words and technical drawings. Our ME 1770 course, Introduction to Engineering Graphics, is cross listed with the schools of Aerospace, Mechanical and Civil engineering and is required of all freshmen. The students are introduced to technical communication using paper drawings and Computer Aided Design (both 2D and 3D) software through a 3-hour lecture and 2-hour lab per week.

The ME 4041 course (Interactive Computer Graphics and Computer-Aided Design) at Georgia Tech is targeted at junior and senior level students of the George W. Woodruff School of Mechanical Engineering. This course has an annual throughput of over 120 students and is taught every semester. The objective of ME 4041 is to provide hands-on exposure to computer-based modeling, design, and analysis techniques in addition to theoretical formulations. Three hours of lectures every week introduce them to the principles of geometric modeling and the finite element method. Two hours of weekly laboratory gives them practical applications using the I-DEAS Master Series suite of CAD/CAE/CAM tools by EDS-PLM Solutions or Pro/Engineer suite of tools by PTC of Needham, MA. The students demonstrate their learning with a group design project involving CAD and CAE applications in thermal and mechanical design. A Product Data Management (PDM) system was implemented in the computing environment to support the design projects and foster teamwork.

The PDM databases and related files are setup on a SUN workstation in the A. French building of the College of Engineering. The CAD/CAE executable files are loaded locally on:

- 22 personal computers in the MRDC building of the School of Mechanical Engineering running Windows 2000
- 25 SUN workstations in the A. French building running UNIX

All of these facilities (see Figure 1), including the student dormitories located on the west campus are connected via a T1 ethernet network. This gives students access to their data from any computer on campus via a web browser or locally installed software. The PDM handles the data conversion processes (from UNIX to NT and vice-versa) and file locking. As students build parts, others can conduct the assembly process and other tasks (e.g. finite element analysis) working on referenced parts with read-only privileges. Working in this environment, 2 students designed and analyzed the excavator

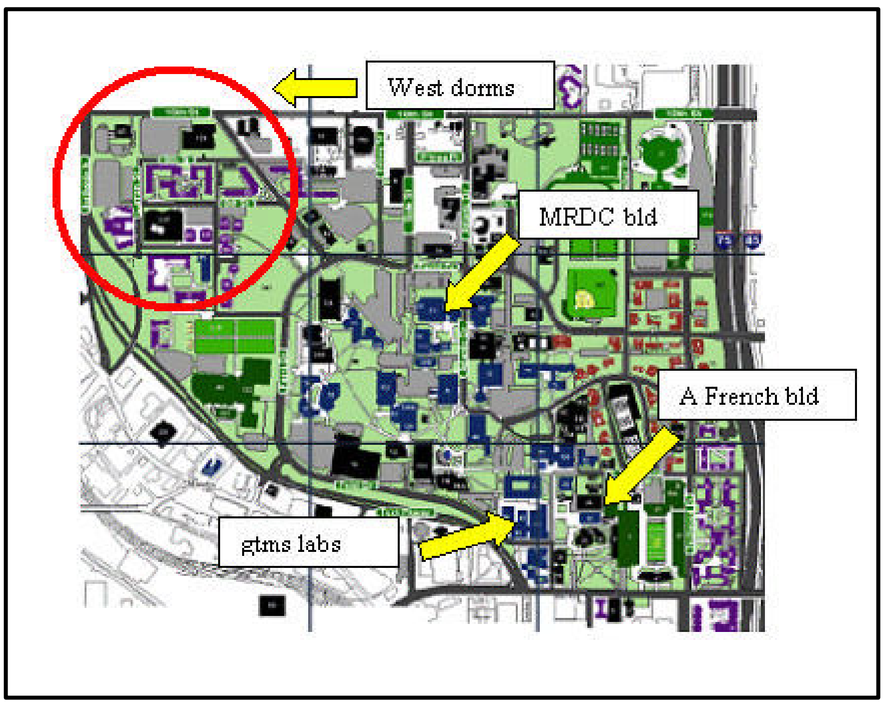

Figure 1. Computing Environment at GT

shown in Figure 2 during the spring semester of 2003 and 18 students collaborated to virtually build the mini-Formula racecar for the gtMotorsports club shown in Figure 3.

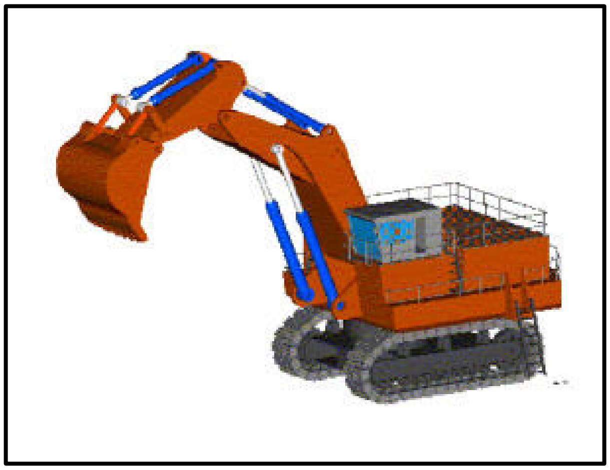

Figure 2. Excavator

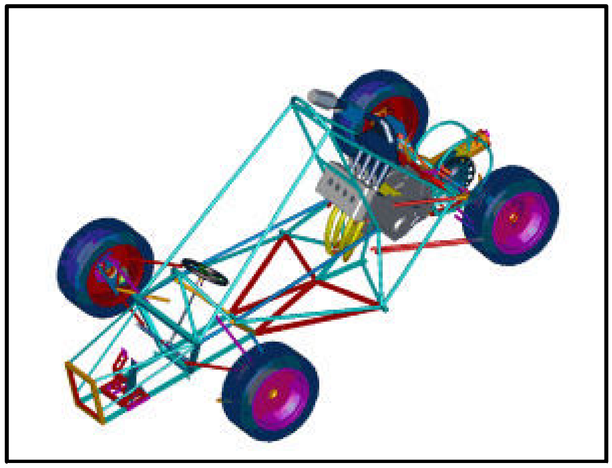

Figure 3. mini-Formula racecar

III. Pilot Distributed Collaborative Engineering project with UMD

Just as it was a logical decision to move from paper drawings to CAD, our current state of distributed collaborative projects is the next logical step in the evolutionary progression of engineering education. Typical computer supported engineering involves a linear design process involving rework and many iterations. After the requirements are formed, the geometry is modeled and analyzed. If changes are necessary, the design is reworked and reanalyzed until the design specifications are satisfied. Then a prototype is built and tested and the results documented. Sometimes the prototype sparks rework in the modeling arena and the process loops until a satisfactory design is achieved.

In a competitive development environment, a linear design process such as this can be very costly. It is generally accepted as fact that the revenue generated by the average product in the first 2 years accounts for 35 to 50% of its lifelong income potential so being first-to-market is crucial to recouping R&D expenditure. It is also accepted as fact that 80% of the costs of a product are committed during the first 20% of the product development cycle. Poor decision making during the conceptual phase causes not only a waste of resources but also is a major cause of rework and fixing problems late in the development cycle can increase costs exponentially. For these reasons, corporations are turning from a linear or sequential development cycle to a parallel cycle in which all participants in a product's development work collaboratively throughout the entire lifecycle. The key to making this work effectively is Product Lifecycle Management (PLM), making information available at all times to all participants.

To introduce PLM into our curriculum, we implemented a Distributed Collaborative Engineering (DCE) project with colleagues at the University of Maryland - College Park. The decision was made to reverse engineer an existing product that could be readily obtained by both schools from the local home improvement store. We planned for the project to proceed as follows: GT would function as the OEM building CAD models of the mechanical gear components of a cordless screwdriver using Pro/Engineer.

UMD would function as the design team; UMD team 1 (UMD1) would rebuild the handle assembly of the existing model in CAD, and UMD team 2 (UMD2) would create a completely new handle assembly. All documents would be shared using a PTC ProjectLink PLM server installed at Georgia Tech. A weekly teleconference would be conducted every Friday to assess the project's progress and decide on future work. Collaboration using ProductView, a lightweight viewer component of ProjectLink, would also be done as appropriate. The division of responsibilities can be seen in Figure 4.

Figure 4. Division of labor

That was regarded as a great platform for developing the engineering education of the future. Through this project we could:

- Facilitate real time sharing of pertinent design information
- Address barriers to effective teamwork and communication
- Understand prime-supplier relationship in product development
- Incorporate more IT in undergraduate and graduate courses
- Deploy latest CAx/PxM technology at universities
- Study aggregate project management
- Understand team interdependence
- Explore top-down and bottom-up design issues
- Understand barriers to integrating different technology
- Explore standards to facilitate information exchange (STEP)
- Understand security issues relating to data management
- Develop guidelines/best practices for integrating PLM into the design process

The collaboration server was installed at Georgia Tech and its address was registered with the Georgia Tech DNS as ptc.cad.gatech.edu making it accessible via the Internet. Due to limited funds, the ProjectLink server was actually a triad of hand built machines: each PC had a 1GHz Pentium III CPU with 1 Gig of RAM running Windows 2000 SP3.

The first PC was loaded with:

- Windchill ProjectLink 6.2 DSU3
- Apache 1.3
- Tomcat 3.2.3
- Aphelion Directory 2001

The second PC was setup as the database with Oracle 8i Server Enterprise Edition.

The third PC was setup as the CAD visualization server with Pro/Engineer 2001.

Pro/E 2001 was loaded locally on workstations for each team to use. A CAD client was downloaded from the ProjectLink server and installed onto each machine to facilitate the uploading and downloading of parts and assemblies directly from within Pro/E. Other documents such as reports and presentations were uploaded via a web browser.

The server triad was simultaneously utilized by 40 students at GT sharing CAD data in ME 4041.

The participants of the project were:

- GT - extension of ME 4041 (Interactive Computer Graphics and Computer-Aided Design) one faculty advisor and one student engineer/project leader
- UMD1 – project in ENME414 (Computer Aided Design) one faculty advisor and two student engineers
- UMD2 - special problems course one faculty advisor and one student engineer

The master schedule was created as a PowerPoint document and uploaded to the ProjectLink server along with meeting notes so that project members could revise it as needed. Typically this was done following the weekly Friday teleconference. At the initial meeting it was decided that the project proceed in the following order:

1. GT begin modeling interface components and UMD1 begin modeling lower handle components
2. UMD1 begin modeling intermediate components when GT completes interface components
3. GT complete upper parts and assembly
4. GT begin working on complete assembly adding intermediate components and lower assembly from UMD1
5. Design review
6. UMD2 begin work on lower assembly
7. Design review

The GT group purchased two identical power screwdrivers and mailed one to UMD. With the server in place, all participants were emailed a username and password to access the ProjectLink site. The GT team disassembled a cordless screwdriver, took digital pictures of each component, and compiled a

PowerPoint document detailing which pieces were to be built by which teams. The initial meeting was held via teleconference on Friday February 14. The semester progressed as follows:

Week 1	Initial team meeting to discuss schedule and division of work.
Week 2	Seed geometry from GT built and uploaded along with pictures of parts outlining responsibilities.
Week 3	UMD1 built CAD components of the bottom black handle assembly GT: Spring break.
Week 4	UMD1 completed and uploaded CAD components of the bottom black handle and uploaded a list of the components created (in Word format). GT modeled motor for the casing assembly.
Week 5	UMD1 completed CAD components of the top orange handle assembly. GT completed all components.
Week 6	UMD: Spring break. GT completed assembly of gear components.
Week 7	UMD1 completed CAD components of the top orange handle and uploaded a list of components. UMD1 completed bottom black handle assembly. GT: Completed assembly of motor and motor casing to the gear component assembly.
Week 8	UMD1 completed top orange handle assembly. GT completed the assembly of the upper and lower handles with the gear assembly.
Week 9	Design modifications and enhancements of both the bottom and top handle assemblies. GT: Finalized additional assembling and worked on animation.
Week 10	Phase 1 completed, review phase 2 started.
Week 11	UMD2 built new handle assembly and components using GT assemblies.
Week 12	Phase 2 completed.

The DCE project was a resounding success. Two different configurations of the screwdriver product were successfully developed integrating components and assemblies created collaboratively by distributed teams (see Figures 5 and 6). Team members who never met face-to-face shared CAD files in real-time using ProjectLink. Using ProductView team members conducted virtual design reviews in collaborative sessions and formed a shared mental model of the project landscape. Assemblies were built and checked for tolerance and fit; parts were sectioned and measured for accurateness. Professors extended the reach of their influence and experience to students beyond the walls of their schools. We successfully spanned the distance barrier and overcame the two-week difference in our academic schedules. We developed new paradigms for fostering collaborative product development in an academic environment.

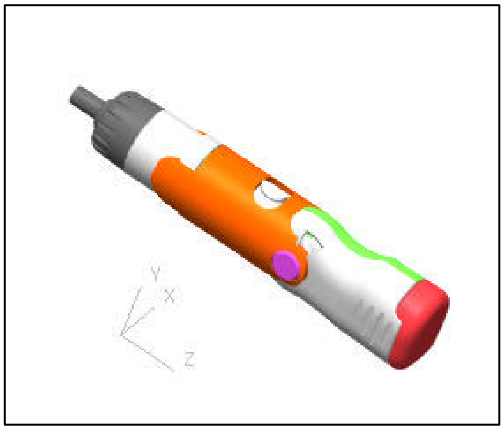

Figure 5. GT-UMD1 Assembly

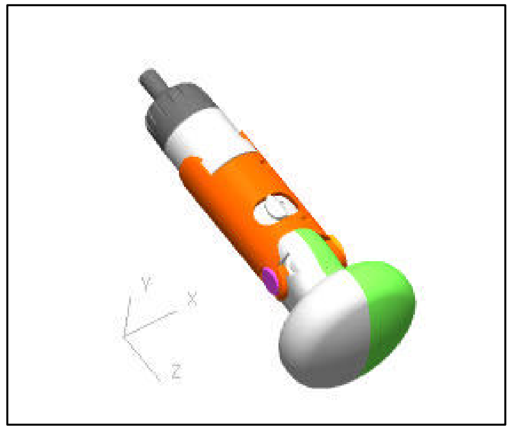

Figure 6. GT-UMD2 Assembly

We successfully integrated PLM into a traditional engineering course (ME 4041) to promote teamwork and collaborative design. Eight student project groups in were trained on cutting-edge design methodology putting them heads above the competition for industry positions. They learned to use CAD and CAE systems in an integrated team environment and collaborate with students in other courses most notable or ME 4182 Capstone Design course. Many students linked their home machines to the laboratory equipment through ProjectLink and the student edition of ProE. Utilizing the server the students realized increased productivity from the ability to work anywhere, anytime sharing data and collaborating virtually.

Despite our successes, the following issues were noted:
Due to a lack of technical resources, UMD1 was unable to successfully utilize ProductView to conduct design reviews during the weekly teleconference. Some of the issues were related to unsupported hardware and software; untested versions of Windows, and Java conflicts. As a result, a lot of time was spent verbally describing problem areas of the design.

Figure 7. Interference

Formal training to use core software is essential. ProductView does not share the same user interface with Pro/E and essentially is a very different software package. It can be seen in Figure 7 that despite both teams having access to the data and there were problems with part dimensions and fit. The functions of PLM are also not intuitive. Many people are uncomfortable with setting file access permissions and also tend to save multiple copies of files as backup in ProjectLink and locally.

True virtual presentations were not conducted with non-CAD files. Aside from the ProductView collaboration, PowerPoint and Word documents were downloaded from ProjectLink by each team and references were made to "look at page X" with each team locally manipulating a copy.

The true functionally of PLM was not exercised: no milestones were used, no workflows were used, and no progressions of object states were made. This was mostly due to us being untrained with using those functions in ProjectLink and they were viewed as being overkill for the size and scope of this project.

No engineering change orders (ECO) were used partly because design reviews were done virtually with all parties present and participants were uncomfortable using the redlining features of ProductView.

IV. The Distributed Product Development Project with John Deere

The Distributed Collaborative Development Product (DCPD) project is sponsored by the John Deere Corporation through their Southeastern Engineering Center in Charlotte, NC. Expanding on the initial work done with the power screwdriver, the objective of this study was to develop an amphibious utility vehicle based on the existing John Deere Gator product. A comprehensive analysis would be conducted to develop and deliver a new product in an academic environment over the span of two years. PTC returned as the principal software/integrator partner and the University of Illinois - Urbana Champaign (UIUC) joined the team (see Figure 8).

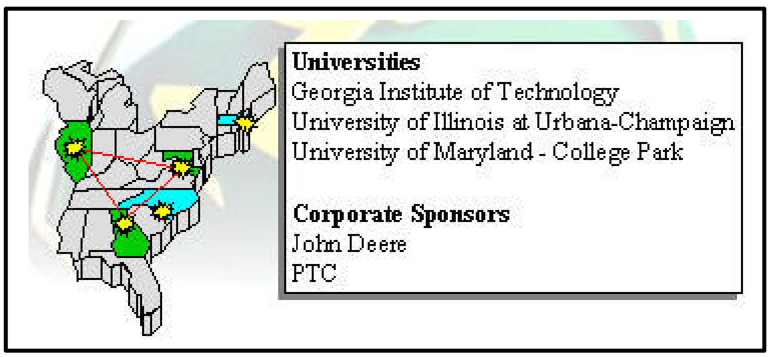

Figure 8. DCPD participants

Phase 1 of the DCPD project began in August of 2003 with the beginning of the fall semester. The hardware platform was upgraded to a true server with 2G of RAM and RAID storage to handle the load of interactive users. The tried and tested software platform (ProE 2001, ProjectLink, etc.) was retained with minor updates and a web based conferencing package, HorizonLive, was added to conduct virtual meetings (see Figure 9).

To start, a series of planning teleconferences were held between the sponsor administrators to set the roles and responsibilities of each entity. It was expected that this phase would be more of a research and discovery activity as the teams learned more about the scope of the project and how to collaborate with distributed members. The project managers at GT and John Deere prepared a Project Plan to serve as a living document to guide the team through the project. A master ProE model of the vehicle was built using skeletons to help define the interfaces between functional subsystems. At GT the project incorporated both the CAx/PxM class (ME 4041) and the senior capstone design course (ME 4182). Five students were charged to analyze the chassis of the vehicle and adapt it for the amphibious function. At UIUC, the team was composed of five freshmen and an upper classman serving as the team leader in a class (MIE 170 - CAD/Design) that introduces students to ProE, design dimensioning and tolerances, and rapid prototyping. These students chose to work on adapting the existing suspension and steering mechanisms to allow the vehicle to be controlled in water and on land. The 3-student team at UMD was responsible for researching and developing/redesigning the engine, power train and fuel and air systems of the Gator for the new mission.

Figure 9. eMeeting in HorizonLive

Virtual meetings were crucial to the success of the project. The team leaders from each of the schools and two project managers (one from GT and one from John Deere) met weekly to discuss design issues relating to the interfaces between the team subsystems. This was accomplished using HorizonLive to share a virtual desktop or ProductView to collaborate on a virtual CAD model. The entire team also met weekly to handle general administrative tasks such as learning the basics of PDM or how to use skeletons in ProE (one of the lessons learned from the DCE project). AOL Instant Messenger was also utilized to facilitate immediate communication with team members. All documents were stored in ProjectLink and updated on a regular basis by those responsible for them.

On Tuesday December 9, a wrap-up of Phase 1 the DCPD project was conducted virtually with the three teams presenting their results and giving recommendations for the subsequent phases. The GT team developed numerous design alternatives based on measured and calculated values and design criteria. Detailed specifications of the design were established based on customer needs and a retrofit floatation kit was designed to attach to an existing Gator (see Figure 10). The UMD team conducted a series of interviews with existing Gator users and developed numerous alternatives for sealing the engine and drive train compartment while maintaining functionality. The UIUC team discovered that the using the existing tires as propulsion was not feasible and that a rudder device would be needed for steering. Overall the teams gathered valuable information on the existing vehicle configuration and what it would take to convert it to perform an amphibious mission. The final recommendation was to make significant design changes to the vehicle. Some of the proposed changes:

- Redesign the chassis using less steel or lighter materials.
- Increase the buoyancy of the vehicle.
- Add a rudder for steering.
- Replace the pedals with hand-operated controls.
- Use tires with larger treads.
- Drive all wheels of the vehicle.

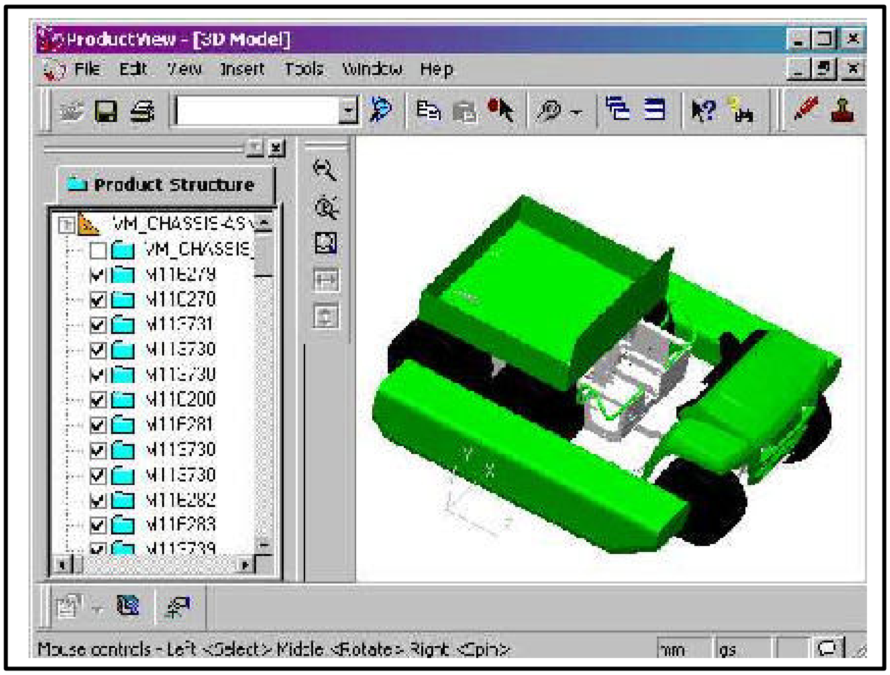

Figure 10. Gator with Pontoons viewed in ProductView

V. Conclusion

Conducting multidisciplinary distributed collaborative projects in an undergraduate curriculum is essential to developing the workforce of the future and improving the productivity of Industry. Students of all disciplines must understand how every facet of the product development environment in interrelated and leverage knowledge accumulated from other activities. We have effectively accomplished this through the introduction of Product Lifecycle Management into our curriculum to conduct several distributed collaborative projects with other universities. The students involved found that these projects provided them the chance to apply and better understand tools they learned in traditional classes. They also learned the cost of being dependent and waiting for other teams to make decisions before they can act. All students enjoyed the ability to interact with engineers from Industry in an active project without having to take time off from school.

The next phase of the DCPD project is already underway with lessons learned from the previous phase being used to direct present and future endeavors. Procedures and methodologies for conducting distributed collaborative engineering projects are being refined and transferred to other universities through the DCPD project and conferences. Students from other disciplines are being actively recruited to augment and enhance the product development environment and we hope to deliver a physical prototype of the amphibious utility vehicle fabricated by students. This is just the beginning of an exciting chapter of discovery that will enable us enrich the student experience and shape the engineer of the future.

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