Session

Rapid Prototyping Cases for Integrated Design and Manufacturing Engineering Education with 3D Internet Support

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Abstract

The focus of this paper is the Rapid Prototyping (RP) process, presented and educated using novel 3D interactive, browser readable multimedia.

Rapid prototyping methods range from hand crafted objects that are often animated, to CNC (Computer Numerical Control) machined parts, to CAD 3D models, to physical clay models that are hand or robot crafted in the automotive and aircraft industries. Rapid prototyping has many other integrated physical and intellectual domains, including software.

This paper introduces our knowledge management and teaching / learning methodology. Furthermore, to some extent we discuss our object / component knowledge documentation architecture and offer real-world examples, mostly during the software demonstration part of this paper, of this industry/academia sponsored R&D effort.

Introduction

Rapid prototyping in engineering, IT, manufacturing, and other fields is an important area of science and technology. These should be communicated to everybody who is involved in product innovation, product creation, integrated product and process design (IP^2D), engineering management, and product marketing.

In the industrial world leading companies are discovering that besides minimizing design and manufacturing costs while maximizing quality, they can achieve competitive advantage by introducing new, innovative products that satisfy individual consumers on a global basis. Gains of such 'hot new products' in academia, as well as industry can not only increase the company's market share but can create an entirely new market category, in which the company is the leader, therefore enjoys the efficiency gains by orders of magnitude ([1], [2], and [3]).

The primary delivery mechanism for the above outlined system, includes case based education and knowledge documentation of design efforts, including extensive rapid prototyping to avoid unwanted designs.

At the beginning, the key value of this process is cost savings, customer satisfaction and revenue growth.

As soon as the factory, or organization understands the benefits of web-enabled enterprise processes that share resources, applications and data, the opportunities for further waste reductions and growth are even more dramatic. This is the stage when the e-business gradually becomes a network of connected lean and continuously knowledge documenting/ distributing/ knowledge managing and learning businesses.

On a parallel tract, in education, the created CBL (Case-based Learning) Library is an effective method supporting outcome-oriented quality problem solving and assessment because it forces both the student as well as the tutor to focus, and then create new wealth, and follow US ABET (Accreditation Board of Engineering and Technology in the USA), and European educational principles.

As our validation results, and the over thirty supporting and collaborative enterprises, the academic institutions, and the thousands of undergraduate and graduate students clearly indicate, our solution can be applied to satisfy a large variety of knowledge documentation and learning, as well as hi-tech product marketing needs.

Class Architecture, Creative Innovation and Needs Analysis

There are several definitions of design knowledge management. In our view none of them can fully grasp this very complex research issue, therefore, for our practical purposes *design knowledge management attempts to succeed by combining correlating data and information produced by information processors,* such as computers, embedded 'machine, versus human-smart' devices, and others, as well as creative, innovative, sensing and reasoning human beings (who still drive the show…), in our case experts in integrated design and manufacture.

The concluding fact is that there is a tremendous need to create some order in this growing data chaos that academia and industry produces, and then turn this into useful information, that could and should be turned into knowledge to be reasoned upon for the benefit of creating new intellectual, as well as fiscal wealth ([4], [5], and [6] to [8]).

The focus of this case is Rapid Prototyping (RP) processes and related knowledge management. This is an important area of science and technology that should be communicated to everybody who is involved in product innovation, product creation, product and process design, engineering management and advanced product marketing.

Engineers, managers as well as IT (Information Technology) professionals should learn by working through this case, despite the fact that their focus and approach are often different.

The important issue about this particular case is that it illustrates methods that do not need a tool, such as a drill, or a milling cutter for making prototypes. This is a very important cost and time saving opportunity for product / process designers, industrial designers, marketing engineers, as well as for manufacturers.

Throughout the Case, the learners are encouraged to analyze their Rapid Prototyping needs by using our generic Requirements Analysis Spreadsheet Template to perform formal needs analysis. Furthermore, they can evaluate the potential failure risks of the proposed processes by employing our Process-oriented Failure Risk Analysis Spreadsheet Template ([9], [10] and [11]).

Our Design-oriented Problem Solving Approach

In terms of communicating a formal design method we raise and attempt to answer product / process design-oriented questions that cover the discussed material, and evaluate the team's performance using our open source spreadsheet templates, as well as the 3D interactive multimedia, with an in-depth discussion based on text, the video-clips and the 2D and 3D animations we have integrated into our eBooks.

Furthermore, as a generic, object-oriented problem solving method (as with all cases in our library) we are committed to the following systems approach that we communicate to young design engineering students, as follows:

- Always analyze the needs and the requirements, the demonstrated processes, methods and systems you have to satisfy. (Note, that we offer our analytical tool, CORA, a derivative of QFD, quality function deployment, to perform requirements analysis.)
- Analyze the actual methods presented. Find the core methodologies, the mathematical models, the underlying engineering (and /or other) science foundation. (Note, that we support these efforts by offering several open-source active code to our learners, that they can execute with their own data to perform such analysis.)
- Analyze the technologies involved. (How is science turned into a practical solution / engineering and/or computing technology? Note, that we support this activity by means of 3D interactive, virtual facility tours and in-depth technology demonstrations on video, explained by subject area experts.)
- Analyze and review the actual processes and the way the process flow is integrated during the product-lifecycle(s). (Note, that we follow an object-oriented process analysis method, from concept to product, including validation and even after-sales support, by following a truly multi-lifecycle engineering

approach.)

- Analyze potential alternative solutions. (Note, that we encourage young design engineers to come up with novel, workable alternative design solutions. Methods and technologies, such as process gap analysis, and CAD / CAM simulation can help this activity.)
- Analyze the benefits and the disadvantages of each process / solution, including risk analysis. (Note, that we offer our open source process risk analysis software tools for students to explore risks, and eventually reduce them to close to zero.)
- Design alternative methods, processes based on what you have experienced / seen, and learned from our expert presentations and demonstrations in real-world laboratories and factories.
- Design an integrated system, based on what you have analyzed in this case.
- Work in a multi-disciplinary team and exchange ideas openly, and in an ethical fashion. (Note, that our students receive an eLearning pack, that typically includes four companies they have to collaborate with to learn about team-oriented problem solving on a global basis.)
- Understand the boundaries as well as the tremendous potential of new ideas and developments by working on this case. (Realize that in order to survive and win, you must add value, that customers appreciate).

At various levels of this virtual product/ process demonstration we stop and trigger the learners' thoughts. We focus on one or more of a variety of different integrated product / process design-related issues, we call them 'views of the design', including the following:

- Requirements / needs analysis
- Product / process design
- Manufacturing / assembly / disassembly
- System integration
- Networking/ Internet
- Software engineering
- Total quality
- Engineering management
- Maintenance
- Environmental
- Sustainability
- Operator training and customer support
- Ergonomics / Human factors
- Marketing view, and others.

In addition to our integrated product / process analysis views, the learners will typically analyze and review the way the given attributes satisfy customer needs, and simultaneously stay within time, budget, quality and other constraints. The attributes we are simultaneously challenged by are as follows ([1] and [12]):

- Performance
- Reliability

- Cost
- Safety
- Developmentability (i.e. how easy is it to develop an idea, or a prototype 'product' to a real, marketable product?)
- Serviceability / maintainability
- Simplicity
- Interchangeability
- Capacity
- Life cycle, and even more: multi-lifecycle and environmental attributes, including ease of de-manufacturing and disassembly
- Appearance, and others.

To summarize, we promote the thought, supported by analytical, quantitative and open-source computational tools, that the design engineering decision process is about:

- Analysis
- Synthesis
- Evaluation, and
- Execution.

Our Team-oriented Problem Solving Approach

In addition to what we have described above, we encourage team-oriented problem solving and collaboration, by offering rules- for brainstorming, and with the aid of 3D interactive multimedia help the learners and faculty to perform the following activities:

- Clarify the objectives.
- Identify all the tasks you have to accomplish as individuals as well as a team.
- Put the agreed tasks into a logical order.
- Estimate the time and additional resources you will need (e.g. web searching and research time) to accomplish the job.
- Allocate responsibility.
- Review the entire plan before you start using our requirements analysis (CORA) spreadsheet template and adjust / customize as necessary.
- Review the entire plan before you start using our process failure risk analysis (PFRA) spreadsheet template and adjust / customize as necessary.

Having accomplished the above plan, we brainstorm by focusing on the following rules:

- Keep a relaxed atmosphere by choosing a comfortable, undisturbed environment.
- Choose a team leader who has some experience in how a session will operate.
- Organize the appropriate team of 3 to 5 or perhaps up-to 7 people. (If you have too few, or too many the intensity of the discussion will suffer!)
- Summarize the problem / challenge definition again (see list above).
- Generate as many ideas as possible, even if many of them are totally off-beat.
- Give everyone equal opportunity to contribute to the new idea generation

process. (Let them warm up, relax and then roll...)

- Write down every idea... even if some of them might sound crazy. (You can use our CORA spreadsheet template to keep things organized.)
- Allow time for ideas to incubate. Brainstorm in sessions of 30 minutes, or an hour with perhaps a few days between them if, and only if the group still has some steam...

To summarize, the purpose of this library is to be able to work with, and learn from real-life R&D and industrial challenges, including best practices, with the intention of getting things done using sound methods, technologies and collaborative peer group experience as support mechanisms.

The driving force behind this challenging integrated case-based learning method is the acceptance of the fact that industry needs hard working, well rounded, diligent and honest design engineering students, who can become lifelong learning professionals, and then can be viewed as the most important assets of our society.

Advanced Instructional Methods and Solutions

Our approach mirrors real-world issues as closely as possible in an open source, networked virtual classroom (i.e. on the students' laptop monitors), by using various techniques, most importantly the Virtual Product Demo with 3D objects that the students can explore, disassemble and then re-assemble in a matter of seconds, 3DVR (three dimensional virtual reality) interactive objects and 360 degree panoramic virtual facility tours, and high quality accurate videos containing interviews with product / process experts, and time and motion accurate machine / process / system demonstrations.

In terms of delivering our cases we follow the Virtual Product Demo concept, in that we virtually take the learner with us to factories, R&D studios, exhibitions and laboratories and give them interesting demos explained by real-world experts with challenging problems to solve. In all cases we show them high quality, interactive videos and often 3D objects and panoramas so that they can interrogate them and even participate in digital, virtual factory tours.

In terms of challenging to learn and investigate the illustrated case further we give several direct URL (web) contacts, e-mail addresses so that the learner can get in touch with key contacts and start to collaborate. We focus our questions and address exciting engineering, management, and computing science / IT (Information Technology) issues. This approach helps distance learners as well as educators to work with the material in real-world classroom and/or virtually web-networked teams.

Our cases are object-oriented and self-contained; nevertheless, they can be integrated or grouped into different classes of objects in a lean and flexible way, just as a modern software program, or a modern manufacturing/assembly system can be integrated into different environments. This enables learners as well as instructors and managers to 'plug-and-play' our cases in ways they choose rather than the way the author meant it.

The methodology we follow enables basic knowledge transfer enabled with 3DVR interactive multimedia. It is highly interactive, collaborative and enables large groups as well as individuals to gain the same knowledge effectively. Although this method is not for everybody because the problems as well as the solutions are interdisciplinary, often open-ended and can get complex, in all cases our solution will enhance, support and enable a wide range of interactions with real-world challenges.

The benefits of introducing problems for students to solve using cases in a browser-readable 3DVR interactive multimedia format are manifold. The entire learning process becomes more student- versus lecture- or tutor-centered. Students can learn by exploring versus being told, and can have as many goes at solving a problem, or exploring an idea, taking as much time as desired or is available. Mistakes made can be corrected without penalties. Multimedia tools, or a subset of such technology and a variety of media, are available during the learning process ([3] and [6]).

In our system self-assessment is possible. This means that students become more self-critical as they participate, and directly contribute to their own learning processes. Team, group and class assessment is integrated into every module of our programs (supported by active code spreadsheets, often with embedded 3D objects, video-clips and animations) that the students can interrogate to understand either the question(s) or the answers better. Furthermore, in our assessment programs graphs are shown illustrating individual versus group /class benchmark assessment results. This is very useful, in particular for distance learning students, because they feel that they are equal members of the class. (Traditional, as well as e-mail, web-collaborative, telephone and personal-appointment-based tutorial support is available if required).

The entire education process we promote is more suited to satisfy individual needs. Since failure is not exposed in Open Learning situations, fear is not part of the learning and testing process. Students teach themselves, work on their own and the educator's role changes towards a facilitator, consultant and guide, rather than the sole information provider as in the past.

Education does not become boring, because the routine part of the material is taught by the students themselves, by means of the interactive 3DVR multimedia technology, and because the exciting or difficult parts can be reinforced by the instructor. The entire education process is more suited to satisfy individual needs from 'batch size 1 to many' at the same high quality.

To illustrate some aspects of our interactive, 3D browser readable eLearning architecture, and rapid prototyping cases, in **Figure 1**, we present a typical screen segment of a case, in which we introduce various rapid prototyping methods, and a real-world challenge of building a multi-purpose propeller (developed at the ‘Nottingham

Advanced Manufacturing Centre', a multi-million Dollar, first class rapid prototyping laboratory.)

As the screen-prints in Figure 1 illustrate, the left hand side of the screen is usually hyper-linked text and small icons prompting student actions, with the fundamental text content. In the right hand side of the screen, we offer active code, animation clips, interactive videos in 2D and 3D, 3D objects, 360 degree panoramas and virtual facility tours, and others, that enhance the learning process, and together with the text, images and other media re-enforce the subject area.

According to our experiences, such multi-facetted computing support in education offers a well-rounded experience, that is significantly more enjoyable to learn, than using traditional methods. (Please note, that our original screens are in high quality, full screen and full color graphics, that we had to reduce in size and quality to fit the format requirements of this paper. Please visit http://www.cimwareukandusa.com, and then click on the Case Library icon to view these screen-prints in full color and high quality.)

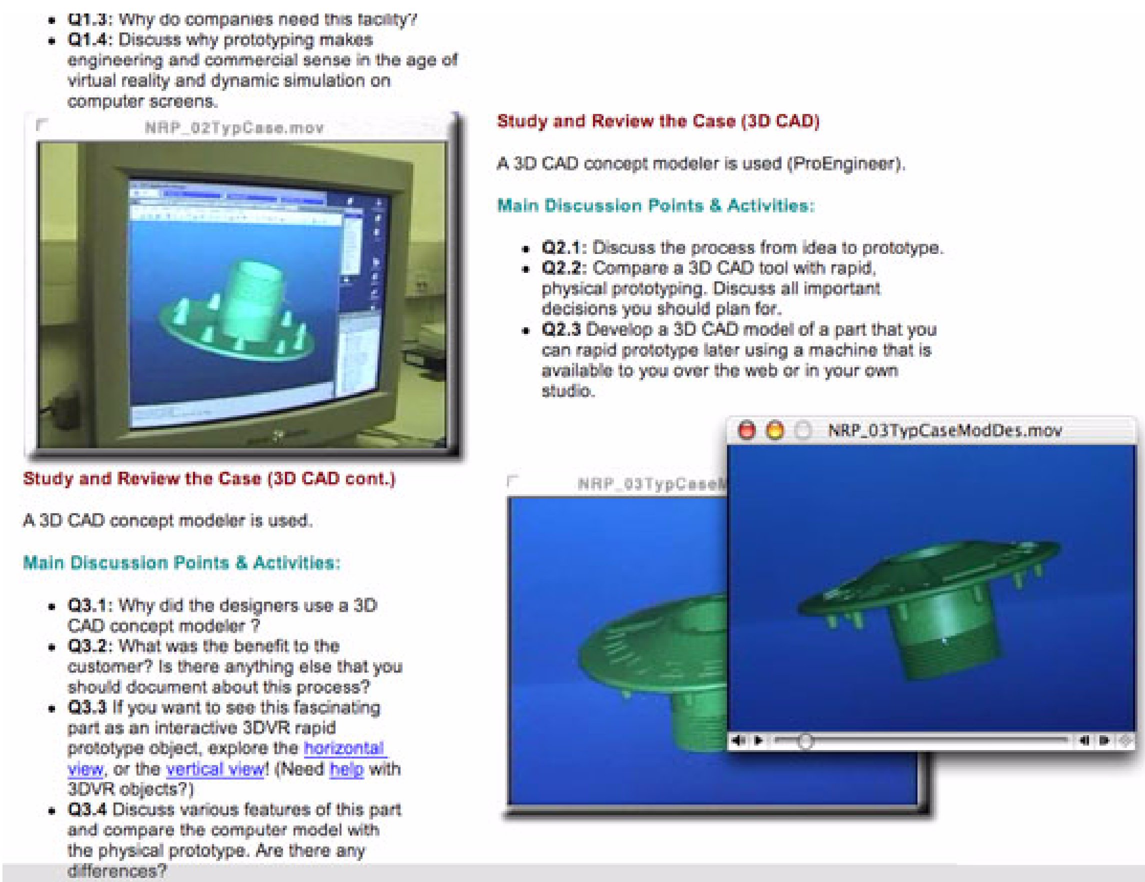

Figure 1. A typical screen segment of our browser readable, interactive 3D multimedia screens in the Case Based Learning Library.

Figure 2 (below) illustrates further screen segments, that enable students to actively manipulate real-world virtual 3D rapid prototyped objects, and explore them according to their own interest.

This approach keeps the students interested in the subject they learn, because they can actively interact with the computer, showing them exciting 3D interactive animations, and active code they can run with their own data, encouraging independence from their tutor. (Please note, that our original screens are in high quality, full screen and full color graphics, that we had to reduce in size and quality to fit the format requirements of this paper. Please visit http://www.cimwareukandusa.com, and then click on the Case Library icon to view these screen-prints in full color and high quality.)

Figure 2 illustrates several interactive 3D virtual reality objects, rapid prototyped propellers, that enable students to explore an-in-depth view of the discussed subject area.

Summary and Conclusions

The driving force behind our case-based learning method presented in this paper is the acceptance of the fact that industry needs hard working, well rounded, well educated, analytical and computationally well equipped, diligent and honest design engineering students, who can become lifelong learning professionals, and then can be viewed as the most important assets of our society.

Our 3D multimedia learning material have been validated and tested in several industry and university (live and virtual) classes, involving hundreds of undergraduate and graduate students at NJIT in Industrial Engineering, Mechanical Engineering, Computing Science and Information Technology, as well as on a wider US and international basis, at Dundee University in Scotland, at Nottingham in the UK, at Imperial College in London, at Old Dominion in the USA, at the University of Michigan, in Ann Arbor, in Sweden, in Hungary, in Mexico, in Hong Kong, in Singapore, in Switzerland, at Kyoto and Kobe Universities in Japan, and at many other institutions and companies world-wide. We are pleased to report that our methods, and several 3D multimedia resources have been adopted for university and company intranets for eLearning.

Due to the open, web-browser readable nature of our approach, each object/module is customizable, extendible and editable. This popular feature allows students and faculty to become simultaneously authors as well as readers. (In order to maintain integrity and quality, obviously, the core documents are maintained permanently only by the document owners.)

The most important design feature of our object oriented system architecture is that there is only one core, reusable electronic document, built of 3D web-objects, and active code, that has to be authored and maintained. This enables a wide variety of users/viewers to occasionally become authors (via the appropriate security gates and web-technology) feeding useful knowledge into the content of the object and component oriented architecture.

This work is the result of several years of on-going research. It started in 1977-78 when Paul G Ranky has developed an FMS (Flexible Manufacturing System) object-oriented database and then later, in 1984 by Ranky at Nottingham and Siemens-Plessey in the UK, and then in 1992 when together with Mick F. Ranky, supported by CIMware Ltd., http://www.cimwareukandusa.com and FESTO Ltd. an interactive multimedia CD-ROM was developed as an electronic support system for servo-pneumatic positioning, as well as part of another project for bio-medical engineering with Prof. T. Pato in Berne, Switzerland. In 1997 Paul G. Ranky and Mick F. Ranky developed a 3D browser readable, virtual computer disassembly method, supported by industry, that has led to several other R&D grants (including major DOD grants for NJIT) and publications, including the 3D Multimedia Case Based Library (1995 to date).

Since then the topic as well as the architecture has evolved into a robust, object-oriented knowledge management architecture with 3D web-objects, supported by several companies and institutions, including FESTO Inc. USA, GenRad, Inc., The Nottingham Innovative Manufacturing Center, IMI, Ford, Rolls Royce, Ratheon, PSE&G, GibbsCAM, GenRad, Cincinnati Machines, Fanuc Robotics, MCI-WorldCom, IBM, Okuma, BMW, Motorola, Sony, GE Fanuc, Yamazaki Mazak, Bosch and many others. Our efforts have been validated and strongly supported most importantly by our undergraduate and graduate engineering, engineering management and computing students at NJIT, and elsewhere in the world, who have worked through different versions of our objects and helped us shaping it to its current, still evolving, nevertheless already mature and very robust truly multi-platform (meaning Apple Mac, OS 9 and OS X, PC Win 98, 2000, NT, XP, Linux and Unix compatible) format.

We would like to thank for the continuous support of our students, the companies and organizations, and are pleased to report that our efforts are moving on with an increasingly positive energy flow in all of us involved.

Live Software Demonstration

During the presentation of this paper at the conference there will be several live software demonstrations, illustrating the novel interactive 3D multimedia approach to virtual rapid prototyping laboratories, demonstrating the benefits as well as the challenges the design engineer faces when using such methods and technologies. Furthermore, we'll demonstrate our various open-source active code programs, integrated with 2D video-clips, 3D objects and 3D panoramas, that a printed paper can never truly illustrate.

Please note, that during discussion periods further, in-depth software demonstrations will be offered, and questions will be answered during the conference using off-line, and optionally wireless Internet access (based on availability).

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