A New Approach for Teaching and Learning About Engineering Process Failure Risk Analysis with IE Case Studies

Paul G. Ranky

Professor, The Department of Industrial and Manufacturing Systems Engineering, New Jersey Institute of Technology, MERC (Multi-lifecycle Engineering Research Center), Newark, NJ, 07102, USA. Email: ranky@njit.edu

Introduction

This paper describes a novel 3D web-browser enabled multimedia library, with active code for teaching and learning about engineering, and other, process risk analysis.

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 reducing risks, getting things done using sound methods, technologies and collaborative peer group experience as support mechanisms.

The audience of this library is engineering science and technology students, engineering management students, design, industrial engineering, design and process engineers, IT students / professionals, as well as biomedical engineering and medical science students.

At its most fundamental level, our library is a

- Knowledge documentation method, architecture, tool and resource, an
- Instructional method characterized by the integrated approach to engineering, science, management, IT, and medical sciences, in which we use challenging 'real world' problems as a context for students (and professionals) to learn critical thinking and problem solving skills, and acquire knowledge of the essential concepts of the course,
- Supported by web-enabled, novel 3DVR (three dimensional virtual reality) interactive multimedia, as well as by
- Active code provided as tools for performing calculations, such as risk analysis, and others, and collaborative analytical reasoning, and with optional self-assessment tools, again integrated with novel 3D interactive objects, as well as text, digital videos and animation, and
- Live, and/or on-line tutor support in an asynchronous fashion.

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 students, and lifelong learning engineering and medical professionals, who are viewed as the most important assets of our society.

In this paper we introduce the principles of our educational methods and solution, and explain and demonstrate (during our presentation) a series of case-based learning modules that encourage reusable interactive multimedia development, team-oriented learning and problem-solving with real-world challenges. Our efforts are supported by over 30 academic and industrial partners, assuring the diversity, the relevance and the quality of this rapidly growing library and teaching / learning method ([4] to [9]).

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 interactive objects and 360 degree panoramic virtual tours, and high quality accurate videos containing interviews with product/process experts and time and motion accurate machine / process / system demonstrations.

The System Architecture of our Problem-based Library

In our PBL library we follow an object-oriented design, therefore our architecture includes case-based library programs that are self-contained, reusable objects built of components. Often these objects and components are text, high quality digital video, animation, 3DVR and animated 360 degree panoramas. They are open source, web-enabled, delivered on the web, or in some cases in CD-ROM or DVD (to overcome transfer rate and in some countries expensive web-access bottlenecks) or fast company intranets for continuous professional development purposes ([1], [2], [3] and [7]).

The ways we present challenges are very similar to the way professional engineers solve problems. This is because we first look at the real-world customer requirement, then we offer one or more solutions by explaining real-world machines, or processes, or systems, or management tasks and then we discuss further development, service, maintenance, integration, connectivity and many other issues. Notice that we do NOT follow the traditional linear, but rather the modern concurrent, object oriented approach to integrated product/ process design.

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 ([11] and [14] to [17]).

Process and Disassembly Failure Risk Analysis

Process (and disassembly) failure risk analysis (DFRA) is a failure mode and effect analysis method. It represents a systematic method developed by Ranky for disassembly processes to identify and minimize potential failure risks / failures of disassembled sub-assemblies, objects and components, and their effects on the customer (meaning internal and external customers). DFRA is a Team Oriented Problem Solving (TOPS), method, aimed at minimizing dissatisfaction, and financial loss.

DFRA is applied during the planning stages of a disassembly process, and then updated on a regular basis to document changes. It addresses negative quality and is primarily concerned with potential events, that can make the disassembly process, or the harvested components fail. Our approach is component-oriented, meaning that as we disassembly the product the DFRA Team focuses on each subassembly and then component.

Our approach helps the engineering team to work through an analytical, quantitative, open-source computational model, to understand the problems process planning engineers, line managers and process operators face, then see the solutions they have come up with, and then apply the learned problem solving skills to other, new challenges by understanding some of the following concerns:

- What could go wrong with the product or the processes involved when disassembling the product, or one or more of its components?
- How badly might it go wrong, and what could the financial loss be?
- Which are the highest risk processes / operations when working on the product?
- What needs to be done to prevent failures?
- What tools and fixtures are required to prevent failures, and reduce the risk?
- What education is needed for line management and operators to reduce, or prevent failures?, and
- Others.

Our generic approach follows the logic, that in industry different failure risks, and/or modes, and their effects are typically analyzed by a team of engineers working with some objective, cross functional teams, representing "fresh eyes", new fields of expertise, and new ideas. In our specific case, for the purpose of this paper, the DFRA Team focuses on disassembly processes of electro-mechanical devices, including PCs.

In order to support the industry-wide rule-based risk rating standardization process for the disassembly industry, we have included three important files (that are hyper linked to the spreadsheet too). These being the rating rules, regarding Severity, Detection and Occurrence. (As an example, consider the rules we use in our risk analysis rule-based system).

Severity is a rating corresponding to the seriousness of the effect(s) of a potential failure mode. Severity applies only to the effect of a failure mode. The purpose of establishing a value of disassembly severity is to be able to quantify the seriousness of failing during one or more disassembly process steps. For simplicity, and in compliance with basic statistical rules, the value range for severity rating is set between 1 and 10, where 1 is least severe, and 10 is most severe.

As a generic statement, one should realize, that a severity rating system is as good as the data it is based upon, as well as that the ratings we provide here could/ should be standardized by industry groups for conformity ([1] to [4] and [14], [15] and [17]).

After the definitions, let us share the rules (shown in the traditional ***IF… THEN… rule*** based, versus table format) for calculating severity rating in our programs are as follows:

- ***If Rating = 1, then*** *this means, that due to the disassembly process performed, there is No Effect on the part/ component, and/or on system performance, and/or on subsequent disassembly process, or operation. Good news, this should be the default value!*
- ***If Rating = 2, then*** *this means, that due to the disassembly process performed, there is a Very Slight Effect on the part/ component, and/or on system performance. In other words, the (internal, or external) customer will not notice the failure, because only a non-vital fault was noticed. As an example, consider surface finish, slight fan noise, or similar 'fault'. It should be noted, that the good quality of our 3D objects allow correct assessment of such 'faults' , as surface finish, even over the Internet at a remote site. (As made up examples please link to a floppy drive 3D object and a metal PC base 3D object).*
- ***If Rating = 3, then*** *this means, that due to the disassembly process performed, there is a Slight Effect on performance, or process operation. The internal and/or external customer will be slightly disappointed, nevertheless no vital fault will be noticed. As an example, consider slight noise, rattling sounds, potential dirt, or upsetting scratches, or various attachments that were put on the PC cover, such as security chains, locks, and others.*
- ***If Rating = 4, then*** *this means, that due to the disassembly process performed, there is a Minor Effect on performance, or process operation. The internal and/or external customer will notice slight deterioration in performance and/or process operation and be occasionally disappointed, nevertheless no vital fault will be noticed. As an example, consider stronger, more upsetting noise from the fan, or occasional stronger rattling sounds, misaligned components, covers, wobbling keys in the keyboard, an inaccurate (i.e. 'jumpy') mouse, and others.*
- ***If Rating = 5, then*** *this means, that due to the disassembly process performed, there*

is, a Moderate Effect on performance, or process operation. The internal and/or external customer will be disappointed, nevertheless no vital fault will be noticed. As an example, consider upsetting sounds, occasionally strong rattling sounds, misaligned monitor, broken speaker, occasionally unreliable keyboard, and others. (As a benchmark example, let us illustrate a speaker, that is actually in excellent condition).

- ***If Rating = 6, then*** *this means, that due to the disassembly process performed, there is, a Significant Effect on performance, or process operation. The internal and/or external customer will be significantly disappointed, fault will be noticed that may cause part repair, or rework. As an example, consider a broken floppy drive door that was damaged during disassembly, or CD drive, that may not be essential to the operation of a PC nevertheless it is considered to be significant, and others.*
- ***If Rating = 7, then*** *this means, that due to the disassembly process performed, there is, a Major Effect on performance, or process operation. The internal and/or external customer will be severely effected, but system will be operable and safe. Fault will be obvious, that will certainly cause part replacement. As an example, consider a keyboard, that failed, or a display monitor that is not sharp at all, or lost a color component, or a broken mouse, broken speaker cabling, and others.*
- ***If Rating = 8, then*** *this means, that due to the disassembly process performed, there is, an Extreme Effect on performance, or process operation in that the device fails to start, or operate. The internal and/or external customer will be severely effected, system will not be operable, but will be considered to be safe (even if it does not start). Fault will be obvious, that will certainly cause part/ system replacement. As an example, consider a hard disk drive, that failed, a networking card that has hazardous chips and/or batteries on it that can leak (enjoy our electronic marking method in 3D overlaid animation), or is unreliable, and often fails, a PC that does not start, and others.*
- ***If Rating = 9, then*** *this means, that due to the disassembly process performed, there is, a Very Serious, Potentially Hazardous Effect on performance, or process operation. The internal and/or external customer will be severely effected, system will not be operable and potentially unsafe. Fault will be obvious, that will certainly cause part/ system replacement. As an example, consider a power supply unit that has failed, or a video card that does not work, and others.*
- ***If Rating = 10, then*** *this means, that due to the disassembly process performed, there is, a Hazardous/ Dangerous Effect on performance, or process operation. The internal and/or external customer will be severely effected, system will not be operable and definitely unsafe. Fault will be obvious, the part/ component will not comply with government regulations, and is hazardous and /or dangerous, that will certainly cause part/ system replacement. (As an example, consider a PC that has no cover on, or a bus cable that has been damaged during disassembly, therefore causing a short circuit situation, a broken motherboard, and others).*

The value entered in the spreadsheet for severity, is used for calculating the Risk Priority Number, the prime indicator for risk detection. When analyzing the RPN value, the disassembly manager, or operator should focus first on the highest values, trace back the causes and effects and try to eliminate them. Then, as a secondary optimization level, the medium and low RPN values should be analyzed and eliminated in the same manner as the highly rated values.

To summarize, the lower the rating the better in this case. The DFRA team should keep in mind the following: 'The better the definition of the wanted characteristics, the easier it is to identify potential failure modes for corrective action.'

Instructional Design and Example Cases

In terms of instructional design for IE (Industrial Engineering) 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 ([2], and [16] to [20]).

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.

Self-assessment is possible. This means that students become more self-critical as they participate directly in their own learning process.

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 vs. 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 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, in **Figure 1**, we present a typical screen segment of a case, in which we introduce risk assessment, and then risk avoidance by means of 3D interactive multimedia. The illustrated screen shows a printed circuit board disassembly process, with overlayed animation in 3D to explain the operators how the risk of damaging the board during disassembly can be avoided ([20] to [23]). 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. (Please note, that due to formatting constraints in this paper we had to reduce the quality of the images. 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 (below) illustrates further screen segments, that enable students to actively manipulate real-world virtual 3D objects, and explore them according to their own interest. (Note, that according to our experience, 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, all under their control. (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).

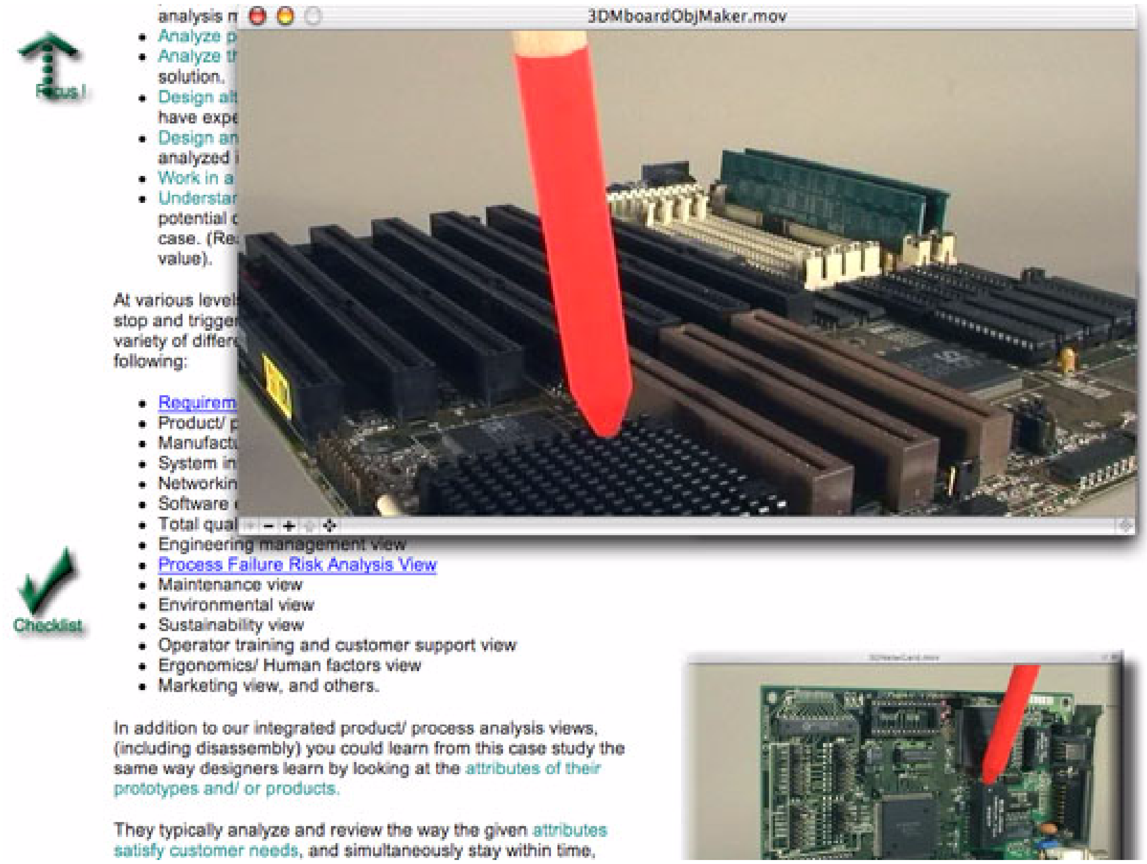

Figure 1. A typical screen segment of our interactive 3D multimedia screens in the Case Based Learning Library.

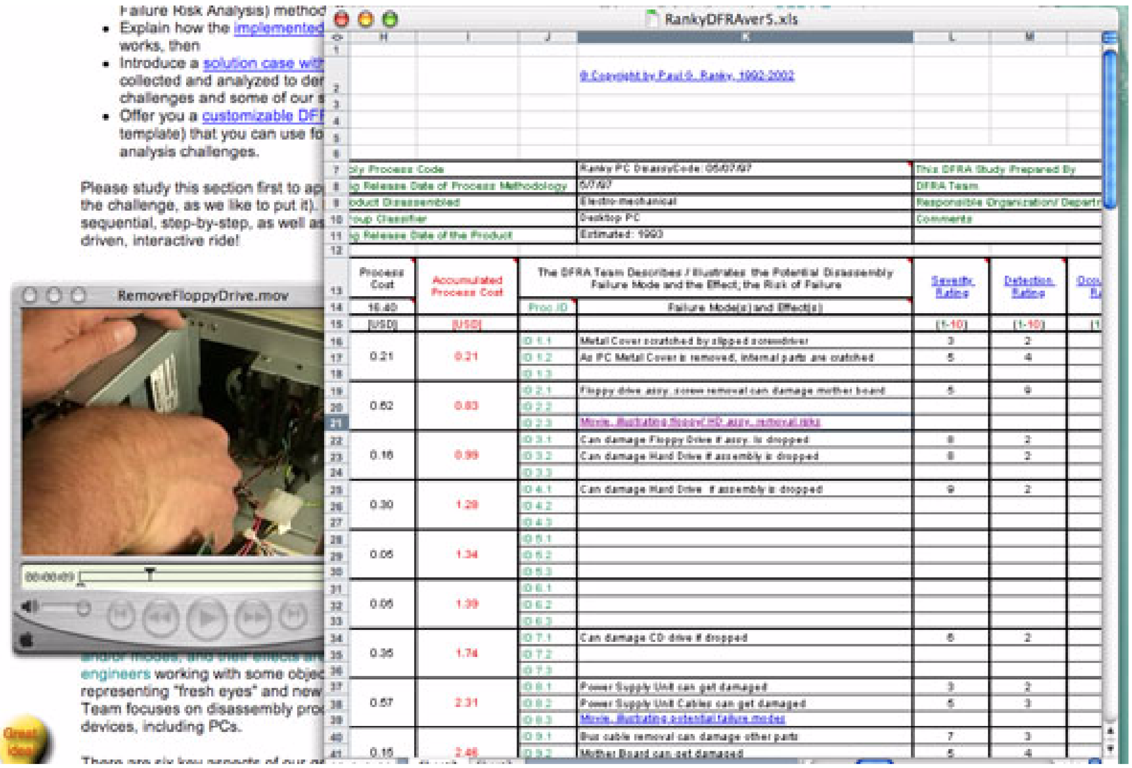

Figure 2 illustrates our DFRA spreadsheet tool-segment, we have developed to calculate our rule-based failure risk analysis algorithms with embedded interactive 3D virtual reality objects, that enables students to explore an-in-depth view of the discussed subject area, and calculate with their own data.

Summary and Conclusions

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 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, as well as the active code and video-clips, that a printed paper can never truly illustrate. Furthermore during discussions further, in-depth software demonstrations will be given, and questions will be answered during the conference using off-line, and optionally wireless Internet access (based on availability).

Bibliographic Information

[1] Ranky, P.G, Deek, F P and Friedman R.: Interactive 3D Multimedia Cases for the Computer Systems and Networking Curriculum in NJIT's I-TOWER Sponsored Wireless Laboratories, ASEE West Point Conference, May 2002, In the proceedings.

[2] Ranky, P G., Golgen Bengu and Gale Tenen Spak: The Development and Application of Synchronous and Asynchronous Technology Based Learning Aids for Undergraduate Engineering Education, The NSF Engineering Education Innovators' Conference, NSF sponsored participation, April 7-8, 1997, Arlington, VA, USA, Proceedings

[3] Frazer, A. and Ranky, P.G.: A Case-based Introduction to the National Electronics Manufacturing Initiative (NEMI) Plug and Play Factory Project; An interactive multimedia publication with 3D objects, text and videos in a browser readable format on CD-ROM/ intranet by http://www.cimwareukandusa.com, CIMware USA, Inc. and CIMware Ltd., UK, ISBN 1-872631-41-x, 2000, 2001. Multimedia design & programming by P G Ranky and M F Ranky.

[4] Throop D R et al: Automated incremental design FMEA, Boeing Co., IEEE Aerospace Conference Proc., 2001, IEEE, May 10-17, 2001, p 73451-73458

[5] Ranky P G: Interactive Multimedia for Engineering Education, European Journal of Engineering Education, Vol. 21, No. 3, 1996, p. 273-293.

[6] Ranky, P. G.: Some Analytical Considerations of Engineering Multimedia System Design within an Object Oriented Architecture, IJCIM (International Journal of CIM, Taylor & Francis, London, New York)), Vol. 13, No. 2, May 2000, p. 204-214

[7] Ranky, P G, Caudill, R. J., Limaye K., Alli, N., Satishkumar ChamyVelumani, Apoorva Bhatia and Manasi Lonkar A Web-enabled Virtual Disassembly Manager (web-VDM) for Electronic Product / Process Designers, Disassembly Line Managers and Operators, a UML (Unified Modeling Language) Model of our Generic Digital Factory, and Some of Our Electronic Support System Analysis Tools, ADAM with IT (Advanced Design And Manufacturing), An international internet registered R&D journal hosted by: http://www.cimwareukandusa.com listed and indexed by the Association of Research Libraries, Washington DC, USA, and the Edinburgh Engineering Virtual Library, UK. USA, 5 p., Vol. 3., May 2002

[8] Ranky, P.G., Das, S and Caudill, R: A Web-oriented Virtual Product Disassembly and Identification Method for DFE (Design for Environment) and Electronic Demanufacturers, 2000 IEEE (USA) International Symposium on Electronics and the Environment, Organized by IEEE (USA), and the Computer Society, USA, May, 2000, San Francisco, CA, USA, Conference Proceedings.

[9] Ranky, P G.: A Multimedia Web-based Flexible Manufacturing Knowledge Management Framework, Japan-USA International Symposium on Flexible Automation, ASME (American Society of Mechanical Engineers), July, 2000, Ann Arbor, MI, Conference Proceedings.

[10] Ranky, P G.: An Object Oriented Virtual Concurrent Engineering Model and Product Demonstrator Case Study, Japan-USA International Symposium on Flexible Automation, ASME (American Society of

Mechanical Engineers), July, 2000, Ann Arbor, MI, Conference Proceedings.

[11] Ranky, P.G, One-Jeng and Surjanhata, H: Digital Educational Knowledge Assets, International Engineering Education Conference, August 2000, Taipei, Taiwan, Conference Proceedings

[12] Ranky, P G, Herli Surjanhata, One-Jang Jeng, Geraldine Milano: The Design and Implementation of Digital Educational Knowledge Assets (DEKA) with Software Demonstration (An NJIT and Industry Sponsored R&D Project. ASEE (American Society of Engineering Education) NJ Spring Conference, April, 2001 (eProceedings)

[13] Ranky, P G: Virtual Concurrent & Multi-lifecycle Engineering Over the 3D Internet. An invited cluster presentation, INFORMS International Conference, USA, July, 2001, (in the Proceedings).

[14] Ranky, P G: 3DVR Component-based User Requirements Analysis Methods and Software Tools for Collaborative Multi-lifecycle Engineering, INFORMS International Conference, USA, July, 2001, (in the Proceedings).

[15] Ranky, P G: An Object Oriented Model and Cases of Design, Manufacturing, and IT Knowledge Management Over the 3D- enabled Web and Intranets, INFORMS International Conference, USA, July, 2001, (in the Proceedings).

[16] Ranky, P G: A 3D Web-based Flexible Manufacturing and Demanufacturing Knowledge Management Model, INFORMS International Conference, Miami, November 2001, (in the Proceedings).

[17] Ranky, P G: The Design and Implementation of a Case-based Learning Library for Engineering, Management and IT with 3D web-objects, Third Annual Faculty Best Practices Showcase, Invited Paper, NJ Higher Education Network, Proceedings, NJIT, Newark, NJ, Nov 9, 2001

[18] Dunkerley, G., Norton, N. and Ranky, P.G.: A Case-based Introduction to IMI Norgren's Reengineering Project at Kenilworth, UK; An interactive multimedia publication with 3D objects, text and videos in a browser readable format on CD-ROM/ intranet by http://www.cimwareukandusa.com, CIMware USA, Inc. and CIMware Ltd., UK, ISBN 1-872631-40-1, 2001-2002. Multimedia design & programming by P G Ranky and M F Ranky.

[19] Ranky, P.G.: A 3D Multimedia Case: Component Oriented Disassembly Failure Risk Analysis, An interactive multimedia publication with 3D objects, text and videos in a browser readable format on CD-ROM/ intranet by http://www.cimwareukandusa.com, CIMware USA, Inc. and CIMware Ltd., UK, ISBN 1-872631-47-9, 2001-2002. Multimedia design & programming by P G Ranky and M F Ranky. (Note, that there are 6 different volumes available at the time of writing of this program).

[20] Gobble, W M and Brombacher, A C: Using failure modes, effects and diagnostic analysis (FMEDA) to measure diagnostic coverage in programmable electronic systems, Moore Process Automation, Reliability Engineering and System Safety, v66, n2, Nov 1999, Elsevier Science Ltd., Exeter, England, p. 145-148.

[21] Russomanno D J: Function-centered framework for reasoning about system failure and multiple levels of abstraction, Expert Systems, v16, n3, 1999, Learned Information Europe Ltd., Oxford, p 148-169.

[22] McCollin, C: Working around failure, Manufacturing Engineer, v78, n1, 1999, IEE, Stevenage, England, p 37-40.

[23] Nquyen, D: Failure modes and effects analysis for software reliability, Proc. of the Annual Reliability and Maintainability Symposium, Int'l Symposium on Product Quality and Reliability and

Integrity, Jan 22-25, 2001, Philadelphia, PA, USA, p. 219-222.

Biographical Information
Paul G. Ranky, PhD Full Tenured Professor, The Department of Industrial and Manufacturing Systems Engineering, New Jersey Institute of Technology, NJ, USA. For a biographical sketch, including current projects and recent publications, many on-line, please visit:
http://www.cimwareukandusa.com/aboutpgr.htm and then hyper-link as appropriate.