A 3D Multimedia Approach to Biomedical Engineering: Low Back Analysis

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

The objective of this research was to adopt our 3D engineering case-based / problem-based teaching, learning and assessment methodology to biomedical engineering, and even to medical science education, following our validated methodology, that enables students to explore engineering, management, biomedical engineering, computer systems and networking subjects in an integrated environment, with the aid of a generic architecture, that includes 3D web-browser readable multimedia, text, images, interactive videos, active codes for calculations, and even self-assessment tools (as spreadsheets, spreadsheet templates, and others).

The developed and validated cases besides traditional teaching and learning methods, and laboratory activities, use browser-readable interactive 2D and 3D objects, animation, videos, 3D objects of real components, virtual 3D disassembly methods of objects, and simulated (virtual) factory tours, and in the case of biomedical engineering virtual 3D internal and external human body virtual tours, that the students can explore and study. Our educational and computational methods introduce a novel approach to developing and running undergraduate and graduate courses in this subject area for face-to-face, honors and distance learning modes.

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 engineering 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.

In the advanced learning environment Case-based / Problem-based Learning (PBL) is performed using web-enabled, 3D Virtual Reality (3DVR) interactive multimedia with optional on-line tutor support in an asynchronous fashion. This allows instruction to be de-coupled from a fixed schedule live classroom, enabling enjoyable interaction, feedback and assessment of learning and problem-solving literally anywhere, anytime. Problem-based learning is by its nature very interdisciplinary.

This learning methodology simulates, and at times replicates, real-world situations and environments. The core of problem-based learning consists of the following fundamentals ([1], [2], [3] and [4]):
Understanding is based on

- experiences with content and context, with the
- learner's goals, the
- educator's efforts, the
- live and/or DL institution's infrastructure support, the
- individual's interest and motivation, the
- society's pressure and support on all of us to do better all the time.

The important fact is that the above factors are inextricably woven together, therefore understanding is a construction that is unique to the individual living in a particular culture, including all stresses and service in the given culture.

Puzzlement is one of the factors that motivates learning, and in our cases we have included several interactive exercises to increase this kind of excitement and to encourage learning.

Social negotiation and the ongoing testing of the viability of existing concepts in the face of personal (and group, peer, and team) experience are the principle forces involved in the filtering, absorption, reasoning and then the evolution of knowledge ([5], [6], [7], and [8]).

In engineering, management, biomedical engineering and information technology, the application of these learning methodologies bring students into situations that combine laboratory experience with real-world business environments, creating integrated and complex systems in which specific problems must be solved. Although this interdisciplinary, open-ended nature makes PBL interesting and engaging, it also poses challenges to instructors and students that differ significantly from standard classroom learning ([1], and [12]).

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. Furthermore, we are using 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 ([13] to [16]).

The System Architecture of our Problem-based Learning 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 opensource, 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 ([6], [11], [13], and [17] to [21]).

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 ([7], and [9]).

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, or human body tours, as in the case of the biomedical engineering programs and eBooks ([8] and [11]).

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), and in the case of the medical programs, biomedical engineering 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.

Specifically, our methodology suggests the following activities, or processes with continuous quality and requirement feedback-loops:

1. Research and analyze the needs, for all key processes, and then
2. Develop a comprehensive object oriented system model.
3. Create a pilot system, a prototype that you can realistically implement, validate, refine, then
4. Create the full system as specified by your customer(s)/ sponsor(s) and then
5. Validate/ test, support, maintain and educate all parties involved.

In more detail, the process by which we can achieve the above outlined and expected results are as follows:

1. Requirements analysis: What does the customer want? (Note, that a 'customer' here is a learner, as well as an educator.) How can we satisfy this need at the highest quality and minimum cost? What are the engineering solutions for satisfying customer needs? How does our competition do?
2. Object oriented system analysis. (This is the 'as is' system scenario.)
3. Object oriented system design. (This is the 'to be' system scenario.)
4. Optional small scale test phase implementation feedback loop of the most important aspects and processes. (This is basically a prototype to be demonstrated to selected customers.)
5. System design refinement feedback loop. (Based on feedback you should refine and improve your design/ system.)
6. Full test phase implementation feedback loop to all key aspects and processes.
7. System design completion.
8. Implementation and system integration. (Note, that this is a multi-disciplinary challenge in most cases.)
9. Final documentation (Note, that we advocate the practice of preparing the documentation preferably on the way, versus after the project, using interactive multimedia and on-line Internet technology. This will help to satisfy customers as well as save time if one needs to update the documentation.)
10. Subject to contract, continuous system maintenance and support.
11. System administration support and optional formal education at all levels to all involved. (Again, the interactive multimedia Internet based documentation could be the same as the distance learning resource material. This will save a lot! The architecture of our open source programs and knowledge documentation methods are good examples for this.)
12. The identification of future R&D and other collaborative/ sales opportunities.

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 ([1]). 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 ([19] to [22]).

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, [21] to [23].)

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, or class size 1 to many' at the same high quality.

The core of our case library is a solid object / component-oriented, web-enabled system design architecture, that integrates reusable objects and components, in the form of text, mathematical text / formula, 2D images, 2D 'clickable interactive image maps (meaning, that if the learner clicks on an image prepared like this, there will be hyper-links, that will take him / her to deeper knowledge levels), 2D interactive digital videos, 2D and 3D animations, 3D interactive virtual reality files, 3D multi-angle virtual reality files (these are 3D objects viewable from multiple angles, meaning 360 rotation, 110-180 degree vertical angle), 3D overlayed interactive virtual reality animation files, 3D panorama objects (these are for 3D interactive virtual facility tours), and various open-source active code for quantitative analysis in MS-Excel, Java, JavaScript, Perl, UML, C++, and others, as well as various educational support open-source code for grading and assessment (including auto-assessment and grading) to support students, as well as faculty.

The simplified class model of our library system design is shown in **Figure 1** (below).

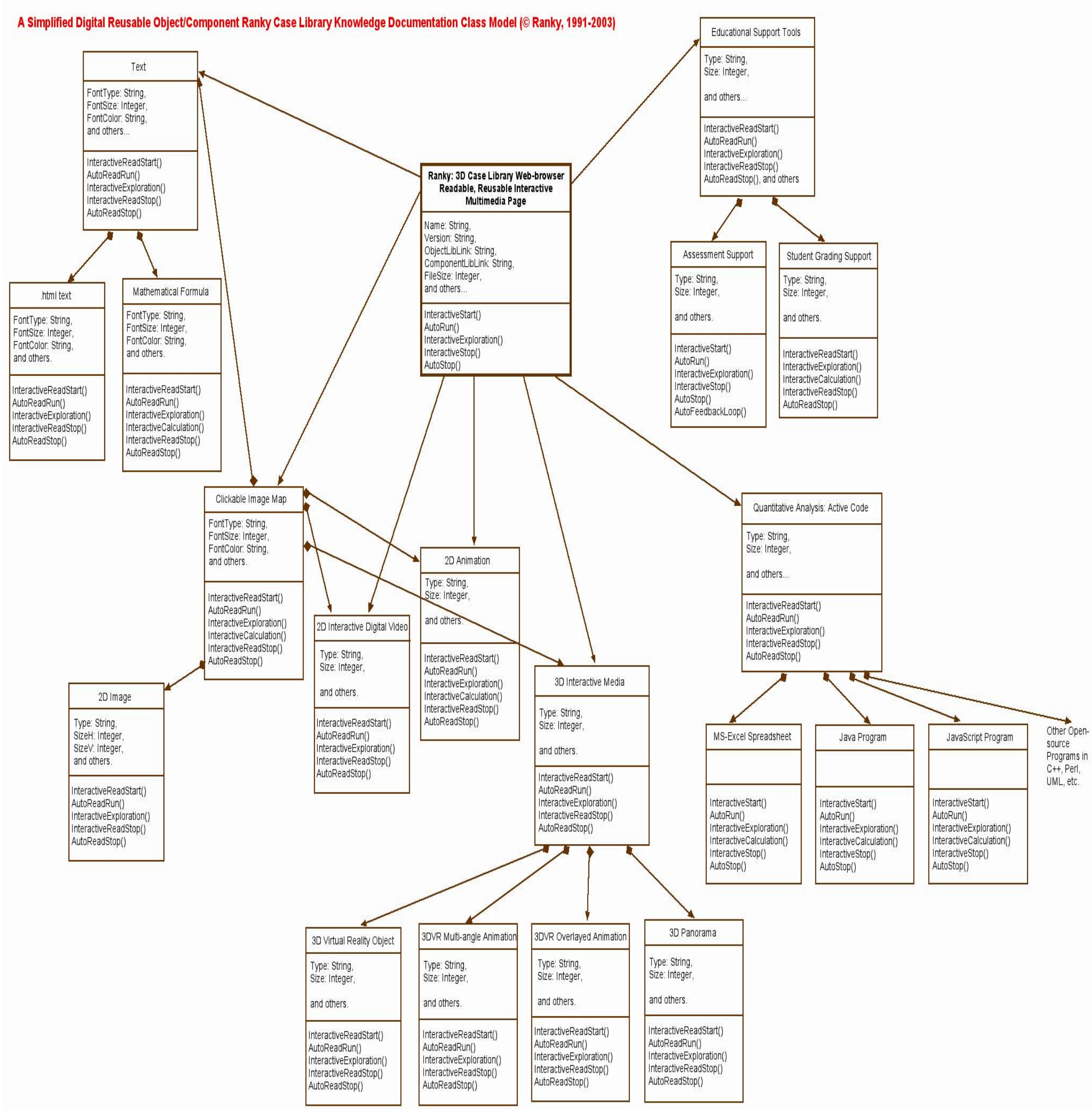

Figure 1. The simplified object / component-oriented, web-enabled system design architecture of our case library, that integrates reusable objects and components, in the form of text, images, interactive digital videos, 2D and 3D animations, 3D interactive virtual reality files, 3D overlayed interactive virtual reality animation files, and various open-source active code for quantitative analysis. (Note, that the implemented, full version of this architecture forms the basis for our knowledge documentation methodology. 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 high quality).

Design, Implementation, Validation and Test

The goal of this low back analysis rehabilitation research and academia sponsored R&D project is to develop a series of case based learning modules that encourage reusable interactive and team oriented learning and problem solving for biomedical engineering, and for medical sciences. Furthermore we see major opportunities in supporting continuing professional education programs, graduate and undergraduate problem based learning, 3D interactive on-line user manual development for operators working with complex instruments, machines and processes, and many others.

This interdisciplinary, open ended nature, and the fascinating 3D virtual reality interactive graphics and Internet-enabled computing tools make his novel case-based learning approach interesting, as well as challenging for all of us, i.e. learners as well as program authors/ creators. Besides traditional teaching and learning methods, and laboratory activities the students of our library are using browser readable interactive 2D and 3D objects, animation, videos, 3D objects of real components, virtual 3D disassembly methods of objects, and simulated (3D virtual) factory and inside and outside the human body tours that students and faculty can explore and study together.

Our methodology does NOT follow the typical textbook case in which all possible methods to be considered are presented, the sample values/ data are well tuned and balanced and there is definitely one solution only... The cases in this library are exciting as well as challenging, because there are often many solutions. We follow an approach that mimics real-world professional biomedical engineering problem solving methods as close as possible in an open source, networked virtual team environment, meaning that the learners can work with the expert(s) on their screens (**Figure 2**), using various novel techniques, most importantly:

- the Virtual Product / Human Subject / Case Demonstrations with 3DVR objects and
- panoramic, interactive 3D virtual tour of facilities, as well as in biomedical engineering the human body (internal and external virtual tours), the
- high quality, accurate videos with interviews with product/ process experts and
- time and motion accurate machine/ process/ system demonstrations in digital, interactive videos,
- active code to calculate with our, as well as user data, and
- the opportunity to interact by e-mail directly with the expert(s) and tutor(s).

In this library we follow an object oriented design approach, therefore the open systems architecture includes the following key design principles:

- Case-based library programs are self contained objects built of reusable objects and components. Often, these objects and components are text, high quality images, interactive digital video, animation, 3DVR and animated 360 degree panoramas.
- They are open source, web-enabled, delivered on CD-ROM or DVD (to overcome transfer rate and in some countries expensive web-access bottlenecks) or fast company intranets, the new emerging opportunity for continuous professional development.

- The way we present challenges are similar to the way professional engineers solve problems. This is because he / she first looks at the real-world customer requirement, then offers one or more solutions by explaining real-world machines, or processes, or systems, or management tasks and then discusses further development, service, maintenance, integration, connectivity and many other issues with several feedback loops, and simultaneously offers discussion opportunities for real or virtual teams.
- In terms of delivering the individual cases in the Library the Virtual Product / 3D Human Subject Demo concept is followed, an innovation on its own, in that learners are taken virtually with experts to factories, R&D studios, exhibitions and laboratories and are given interesting demos and challenges explained by real-world experts who explain one possible solution.
- In all cases the library modules show high quality, interactive videos and often 3D objects and 360 degree interactive panoramas so that learners can interrogate objects, take products virtually apart in 3D, enjoy virtual factory or facility tours and even participate/ collaborate actively by e-mail and other Internet methods.
- In terms of challenging the learner to learn and investigate the illustrated case(s) further, the cases give them several direct URL (web) contacts, e-mail addresses so that they can get in touch with anybody over the web, including any of the authors who have created/ presented the cases.
- In several cases, assessment is supported by spreadsheet-based automated tools, that in case of an incorrect answer hyper-link the learner back to a ‘sorter switch’ routine, that offers a variety of revision solutions, so that the missed material can be revised, and the test re-taken. (Note, that our open-source spreadsheet-based automated assessment tools always offer immediate, and accurate feedback.)
- The assessment questions address exciting engineering, management, computing science / IT (Information Technology), biomedical engineering and other issues, and in many cases document best practices. This approach helps distance learners as well as educators to work with the material in real-world classroom and / or virtual web-networked teams.
- In direct response to the needs of our industrial and academic sponsors, the cases are object-oriented and self contained, nevertheless can be integrated / grouped into different classes of objects in a lean and flexible way (the same way as a modern software program, or a modern manufacturing/ assembly system can be integrated into different environments). This enables learners as well as tutors and managers to 'plug-and-play' the Library cases in the way they choose to, rather than the way the author meant it... This means that our 'typical' readers are problem solvers, as well as readers and authors at the same time... an interesting challenge for all of us. (The 3D low back pain diagnosis eBook approach offers of hyper-linked text, 2D image, 2D image map, 2D interactive video, and interactive 3D objects of humans and anatomy, including interactive 3D virtual tours inside and outside the human body, that the students can interrogate, learn and re-use in this open source architecture. (The collaborating medical professional, and the author of the medical text in this case was Dr. Scott Nadler, UMDNJ, and the Kessler Medical and Rehabilitation Institute in NJ, USA.)

Pelvic shift. (Just click on the image below to activate the 3D Virtual Reality clip. Need HELP! on how to view 3D interactive virtual reality objects?)

Injury mechanics. (Just click on the image below to activate the 3D Virtual Reality clip. Need HELP! on how to view 3D interactive virtual reality objects?)

Lumbar discs. (Click on the 2D image below to view it in full size. Can view it in 3D VR too).

Sagital image, lumbar spine. (Just click on these images to activate the smaller size slidehows. Full size version. Need Help?)

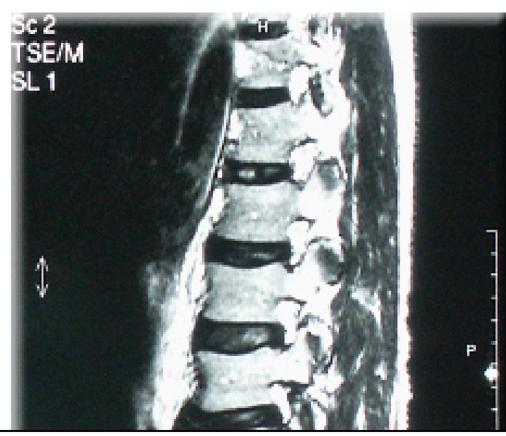

Figure 2. A segment of the 3D low back pain diagnosis case-based biomedical engineering / medical science learning library screen illustrates the fact, that our engineering problem solving, and knowledge documentation / management method can be successfully applied to the human-side of digital factories, and organizations. 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 high quality).

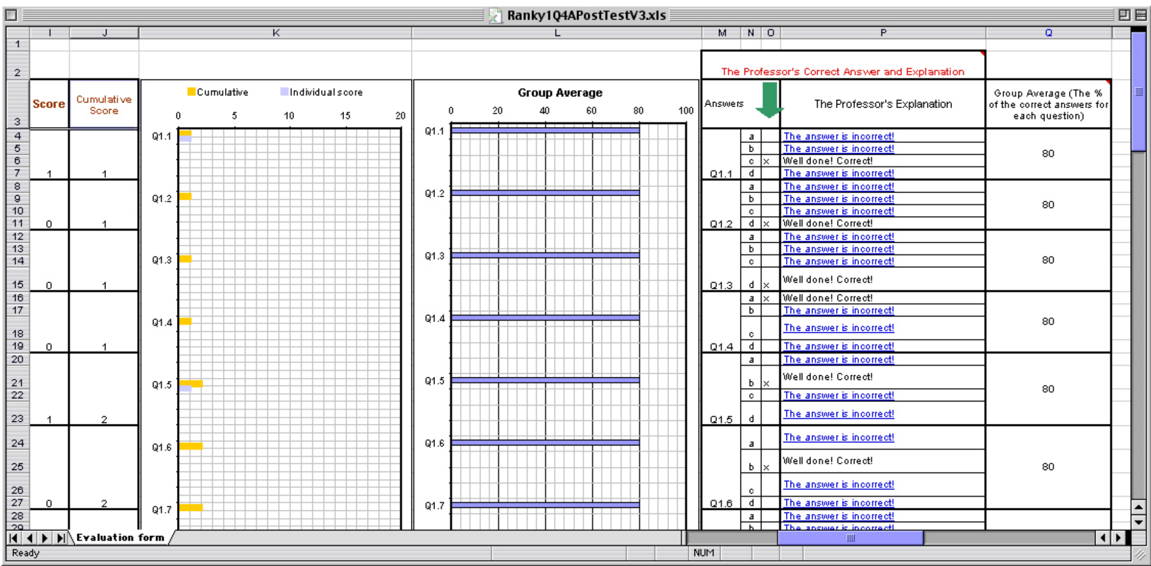

Figure 3 (above) illustrates our post-test method in the Low-back Analysis biomedical engineering eBook, based on automated spreadsheet calculated approach, with several hyperlinks to the appropriate segments of the learning resources for revision purposes. (Please note, that our original screens are 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 high quality).

According to our reviewers, learners and assessors, the created CBL Library is an effective method for outcome-oriented problem solving and assessment in biomedical engineering, and medical sciences, because it forces both the student as well as the tutor to focus, and then create new wealth, and encourage outcome-oriented educational practices. In particular, the implemented solutions aim at the following:

- The overall understanding of, and the introduction to the selected topic including related research and development and application methods in a systems engineering context.
- To introduce some basic terminology of integrated engineering, management, total quality, computer graphics, interactive multimedia the Internet, and in biomedical

engineering cases the medical terminology. (The Glossary of Terms in each case is truly extensive.)

- To develop the ability to apply knowledge of mathematics, science, engineering and object-oriented IT to problem solving, implemented as active code tools, that the users can execute with their own data and then explore different solutions.
- To design / develop and apply system modeling techniques to the solution space of the case and beyond.
- To encourage both the student as well as the tutor to research and explore the case beyond our expectations. (In other words please feel free to make our cases to become 'living documents' reflecting the changes in the way your team thinks and solves problems.)
- To design and conduct physical and / or virtual laboratory experiments, as well as analyze and interpret real measured data.
- To design and integrate systems, built of components and objects, to perform a desired process for a set of defined needs, or customer requirements within time, quality and cost constraints.
- To understand the total quality rules and implications within and beyond the boundaries of the selected case.
- To understand, evaluate, test, learn and apply various software packages for the sake of learning problem solving methods, versus just clicking on buttons offered in the software tools.
- To design / develop / implement and validate an interactive multimedia presentation (web and /or CD-ROM / DVD-ROM oriented) in a specific area of the case using the opportunities of our open source architecture, the 3DVR and panoramic objects, the time and motion accurate interactive digital videos, and optional active code offered.
- To design/ develop some team integration, presentation, communication and knowledge documentation skills of complex engineering systems in a collaborative fashion over the Internet and company intranets.
- To understand professional and ethical responsibility and to communicate such research areas and future trends in the field the case covers.
- To encourage lifelong learning, knowledge creation, knowledge absorption, knowledge documentation, validation, quality control and dissemination processes.

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.

Our new biomedical engineering cases have been validated by over 25 professional U.S. medical experts, as well as several students and conference audiences in the USA, in China, and in Europe.

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 has 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 the NJ Medical School, UMDNJ, in NJ, the Kessler Institute in NJ, USA, 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, in particular UMDNJ and the Kessler Institute, and Dr. Nadler for the support of this biomedical engineering case, 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).

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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.