Chapter 4
Cyber-Physical Systems and STEM Development: NASA Digital Astronaut Project

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Introduction

Cyber-physical systems can be developed to extend the field of medical informatics with an array of sensors that report data to a device capable of making medical decisions to support clinicians with distributed and embedded artificial intelligence capability. Specifically, a prototype of this system can be built at the university level to teach engineering principles including software engineering in context of cyber-physical system specifications, called the *Health Quest* CDSS. Students taking courses in senior design, as well as graduate students, are uniquely qualified to develop the specifications for a clinical decision support system (CDSS) that has both software and hardware components using languages such as Unified Modeling Language (UML) and Systems Modeling Language (SysML) [1], respectively within a cyber-physical system architectural framework. Education of young students from kindergarten to high school (K-12) can take place in a portal, where the design process is observed and mentoring can take place in the Science, Engineering, Technology, and Mathematics (STEM) component of the project [2]. Furthermore, this CDSS system specification and interactive STEM online portal development functions as an extension to the NASA Digital Astronaut Project [3].

Science, technology, engineering and mathematics (STEM) education is considered critical to society in this technologically demanding age. STEM education is considered as an interdisciplinary bridge among technical disciplines. As a result, STEM education eliminates the barriers among the four disciplines, by

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integrating them into a single teaching and learning environment. Therefore, NASA Digital astronaut project is an ideal project to achieve these goals.

This medical guidance system can be built by both graduate and undergraduate students, who can provide guidance/mentorship to K-12 students online throughout all development phases of the *Health Quest* system, which may also include implementation, depending on the budget. The Information Analytics and Visualization (IAV) Center of Excellence at IPFW provides an excellent new environment to build a CDSS that will prepare students for projects relevant to the NASA Human Research Program with support from contacts working on the Society for Design and Process Science (SDPS) [4]. This paper serves as inspiration and ground work for future grant preparation activity in the area of medical applications for cyber-physical systems.

Healthquest CDSS Project Contributing to NASA Digital Astronaut Project

The *Health Quest* CDSS project contributes to the NASA Digital Astronaut Project [3] by preparing university students and K-12 students for careers in Science Technology, Engineering, and Mathematics (STEM). The R&D workflow requirements promote learning in these areas. This is achieved by giving an opportunity for young K-12 students to observe how senior design and graduate students can build a working prototype of a CDSS by registering to an online platform managed by SDPS student chapter members.

Naturally the hands-on experience of architecting, designing, and developing the first system prototype at the university level strengthens and demonstrates their skills in STEM areas by motivating them to work on a project that extends an actual NASA project in the planning stages for the NASA Human Research Program, specifically the Digital Astronaut Project.

Healthquest CDSS Project Vision for STEM

The vision of the NASA project with STEM student work for Clinical Decision Support System (CDSS) is to engage both undergraduate and graduate students in the design/R&D of a medical guidance system for enhanced life support capability. This multi-university initiative, involving the Purdue System, UAB, Auburn, and other universities, can attract grants leveraging the medical resources available at UAB, ties to NASA Digital Astronaut Project and International Space Station (ISS), and the new Information Analytics and Visualization Center (IAV) at IPFW. Significant spillover benefits are expected to STEM initiatives via distance education and online/offline mentoring through the new IPFW and UAB student chapter organizations of the Society for Design and Process Science (SDPS) that can assist in the training of the students through e-learning. This approach is expected to generate a base of focused student activity that can supply enough qualified seniors and graduate students that can contribute to the modular development of the CDSS architecture. This paper reports on some collaborative work with UAB on the information architecture of a CDSS utilizing concept map technology for knowledge engineering of some of the modules using the Semantic Web. NASA outreach via STEM advanced by SDPS is expected to generate more qualified student researchers and freshman enrollment in computer science by stimulating interest and providing assistance both online and offline [5].

Healthquest CDSS Application

Astronauts experience many known and unknown challenges and biological stressors during space travel and in zero gravity that dramatically impact health. Even after the human body adapts to zero gravity, some obvious problems that have been observed to occur include disorientation, bone loss, cardiovascular deterioration, radiation exposure, and food poisoning/infections. In the case of (1) *Disorientation*: Zero gravity causes the body fluids to get disoriented and they tend to accumulate in the chest and the head, (2) *Cardiovascular deterioration*: bulging of the veins in the neck leading to loss of essential body nutrients, including a reduction in red blood cells. (3) *Bone loss*: The significant density reduction of the weight bearing bones causes osteoporosis, whose severity is accelerated due to prolonged stays in space [6]. (4) *Radiation*: Given the fact that the astronauts in space are no longer protected by the earth's magnetic field, the atoms bombard cells thereby penetrating and causing breaks in the DNA sequence which increases the risk for developing cancer. (5) *Food Poisoning/Infections*: Change in diet for the astronauts can lead to food poisoning and slight infections can create unknown deleterious consequences for the astronauts. This knowledge and appropriate countermeasures can be stored in a CDSS using concept maps.

Clinical Decision Support System as Solution for Automated Medical Support

Since it is impossible for a human medical expert to immediately respond with appropriate countermeasures to every medical problem in space, a CDSS could possibly improve the efficiency and response time to a particular emergency, in addition to providing longterm roadmaps to health that astronauts could follow. The CDSS should be able to provide the medical expert with automated recommendations via case based reasoning techniques combined with authenticated medical techniques available globally by accessing distributed knowledge bases, including knowledge stored as concept maps using Web Ontology Language (OWL) [7].

Importance of Concept Maps in Storing Information

Novak and Cañas [8] defined concept maps as "graphical tools for organizing and representing knowledge". These maps include concepts, usually enclosed in circles or boxes of some type, and relationships between concepts; such relationships are indicated by a line connecting two concepts [8]. A concept map allows a computer literate to illustrate an idea, concept, or domain knowledge to be described in a graphical form [9, 10]. Concept maps satisfy the conditions of meaningful learning because they provide a conceptually clear representation of comprehensive knowledge assimilated by a domain expert over time, which can be readily turned into XML and OWL instructions for machine processing [11]. The models generated with the use of concept maps can then be processed by the human mind as well as generate underlying specifications (e.g. in XML format) that can then be transformed into an executable format. Because the concept map provides an efficitive methodology for determining user semantics, the loss of meaningful relationships involved in depicting domain information can potentially be minimized. Second, the concept map model can then be transformed to an executable format in an automated fashion using tools such as Cmaptools; this capability can further reduce the loss of semantics in process modeling.

Overview of Knowledge Engineering Approach Using Concept Maps

The proposed CDSS using concept maps for assisting medical experts should contain some of these basic components:

(i) *Knowledge Base Module*. This component maintains the required domain information on space medicine in the form of concept maps which can later be converted into a suitable XML-based document.
(ii) *Knowledge Extraction Module*. This component is used to facilitate the extraction of relevant information from a database and the required knowledge from the knowledge base.
(iii) *Analysis Module*. This component analyzes the inputs provided by the Knowledge Extraction Module.
(iv) *User Interface Module*. This component handles the inputs on a particular health condition and provides the required information to medical experts.

The following steps are involved in the function of the CDSS:

(i) The medical experts build the knowledge base of diseases, abnormalities and their remedies based on previous experiences using concept maps. These concept maps are then converted into ontology documents.
(ii) The necessary information contained in the ontology document is extracted by the Knowledge Extraction module.
(iii) The medical experts provide the necessary inputs on a prevailing health abnormality of the astronauts in space using the user interface.
(iv) The Analysis Module accepts the information extracted by the Knowledge Extraction Module and clinical data provided by the flight surgeons using the User Interface Module.
(v) The medical experts either receive a particular remedy or a list of remedies for the health abnormality provided to the CDSS.

The knowledge base for the proposed CDSS is assembled based on past experiences of the medical experts and current medical research findings. The medical experts who have acquired years of experience working with the astronauts can readily impart their knowledge into a concept map using the Institute for Human–Machine Cognition (IHMC) CMaptools software. This tool simplifies the task of knowledge transfer in a way that can be machined processed via embedded concepts. The concept maps thus created will have the required information on diseases, their symptoms, and their required remedies.

The concept maps developed by CMaptools can also link the concepts to the relevant documents that can provide the medical expert with some additional information to derive a conclusion in proposing a remedy. The concept maps can be updated periodically to reflect the current knowledge on biological problems in space, in addition to remedies that have already been successfully tested. Since the concept maps are human perceivable from a display, a particular concept map can be readily reviewed and validated by a group of medical experts. Concept maps can be shared and linked together to form a single internetworked series of embedded concept maps to form a very large distributed knowledge base, similar to a neural network.

The knowledge base can have at least two primary components: (a) the visual concept map display and (b) the XML-based ontology file. While the concept map is in human perceivable format, the ontology file provides the machine processible form of information to the system. This information is extracted by the data and knowledge extraction module for identifying the necessary parts of information that can be used in deriving the final outcome and recommendations of the CDSS.

The Knowledge Extraction Module is primarily responsible for extracting the relevant information from the ontology document derived from the concept map. Usually the information extracted from this module is stored in a database which is used by the Analysis Module. This module uses an ontology parser to parse the ontology document under consideration.

The Analysis Module first gathers the required information extracted by the knowledge extraction module. It also gathers the clinical data of the astronauts in consideration. The module then performs an analysis of the clinical data with globally distributed knowledge to arrive at a list of conclusions that recommend solutions as a roadmap to health.

CDSS Grant Proposal: Visual Analytics

The primary medical research focus of the Information Analytics and Visualization (IAV) Center is conducted in the Healthcare Visual Analytics lab which can utilize the new Cave Automatic Virtual Environment (CAVE) technology to develop medical guidance systems using 3-D visual analytics. The CAVE can be used by trained STEM students to collect, analyze, and display data for clinicians, surgeons, and other domain experts when designing a functional CDSS. This type of medical guidance system can provide medical practitioners a technical roadmap with recommendations and rationale on best route of healthcare over a period of time, as well as emergency care. The various factors of input from both the patient and the world are synthesized to produce an output of recommendations displayed in a rich environment connected to remote knowledge sources and inference engines. The driver of this information processing is provided by the patient, detailing information on their health, and by the world, expediently reporting on advances in medical knowledge, building on the Unified Medical Language System (UMLS) [12] and recent advances in Web Services and Cloud technology.

The customized visual report and analysis of the data is provided by Artificial Intelligence (AI) modules with specific algorithms that can utilize available computation methods such as Matlab's Neural Networks and Fuzzy Logic toolbox. Semantic Web technology using concept maps and intelligent agents can be utilized to access global knowledge repositories to be translated from languages like Japanese and German to keep the system updated on most recent medical advances for automated processing and inferencing of new medical recommendations for users of the CDSS. Knowledge engineering techniques can be used to develop concept maps that store domain expertise for future recommendations and machine learning techniques utilizing Semantic Web and XML. Applications of this research range from automated drug discovery to onboard spaceflight medical diagnosis with collaboration opportunities existing with various companies, hospitals, and universities at the forefront of medical research.

The IAV Center will be able to utilize the advances made in the Digital Astronaut project, which is currently in the planning stages at NASA [3]. The comprehensive, mathematically based, digital representation of the astronaut will enable simulations to be conducted on space health under adverse conditions anticipated in space travel and under zero gravity. These detailed simulations of the astronaut's biological systems under various artificial stressors can expose unanticipated problems before they happen that can be addressed by a CDSS in advance.

The Digital Astronaut Project Extended by the Health Quest CDSS Project

The Digital Astronaut Project simulates human physiological function with enough transparency to formulate automated medical advice based on results from sensors that collect data and populate a rich database of dynamic health functions for an individual. This medical information can be analyzed automatically to produce a set of medical countermeasure recommendations for health optimization in microgravity gravity and conditions unlike Earth. However, the *Health Quest* CDSS system is an extension to the NASA project for conditions that occur in terrestrial gravity as well. Hence, STEM students have an opportunity to experience this type of project first-hand at the university level by developing a medical guidance system prototype that will prepare them for careers in medical informatics and software engineering.

SDPS STEM Online Portal Managing Project and K-12 Participation

Ongoing educational STEM activity can be managed by the online portal set up for the project similar to CPS virtual organization [13]. All IEEE documentation, design standards, implementation, and team collaborations will be done in this environment in full view of participating K-12 students so they can observe first-hand how senior design students can build a real working prototype of a CDSS system before graduation, according to prevailing software engineering industry standards. The online student portal can be managed by the STEM module of the SDPS student paper at IPFW. This organization serves as a platform to advance outreach activities via an interactive online portal, as a follow up to NASA outreach developed during the ASGC NASA Fellowship at Marshall Space Flight Center (2004–2006).

Health Quest Project Goals

Student led teams will be able to utilize industrial methodology for detailed design and implementation by developing the medical modules for the *Health Quest* system for full integration with other modules developed by several teams working in parallel according to a core architectural design based on IEEE standards.

STEM Experiential Design Process to Meet Industry Standards

Industry standards are important for senior design and graduate teams comprised of many student roles (e.g. project manager, chief architect, systems analysts, UML/SysML [1] designers, Object-oriented programmers). All phases of the IBM Rational Unified Process (RUP) [14] methodology with Axiomatic Design Process [15] using Software Engineering Body of Knowledge (SWEBOK) [16] and Project Management Body of Knowledge (PMBOK) [17] are studied, utilized, and executed from inception to transition phase, including formatted documentation according to IEEE 830 Software Requirements Specifications documentation, IEEE 1016 Software architecture/Design documentation, and IEEE 1058 Project Management Plan documentation. UML, SysML and the Unified Medical Language System (UMLS) [12] can be utilized for the detailed design phase. Tools include Institute for Human Machine Cognition (IHMC) Cmaptools [7] for project organization and version control, Visio/Telelogic [18] for application architecture and detailed design, Acclaro Design for Six Sigma (DFSS) for the information architecture, including hierarchical decomposition of functional requirements/ trade-off analysis/design matrix generating UML classes/dependency structure matrix (DSM) generating configurations of components and interfaces for the system architecture. Standard risk and project management techniques for validation and verification are developed, e.g. Quality Function Deployment (QFD), Failure Mode and Effects Analysis (FMEA), Probability Risk Assessment (PRA), Fault Tree Analysis (FTA), and Theory of Inventive Problem Solving (TRIZ) [19]. The Architecture Decomposition View (ADV) in Acclaro DFSS can be implemented with a Work Breakdown Structure (WBS) methodology in a standard tool like MS Project for Gantt charting and task assignments [20].

STEM Student Team Selection Process and Deliverables Format

The most qualified STEM students at IPFW may be identified and offered opportunities to receive funding to develop each phase managed through the portal and team collaboration tools (e.g. Basecamp). As deliverables, student teams may produce a project binder and CD for all work completed, by adapting the syllabus of the senior design course CS 360/460 sequence at IPFW. This comprehensive documentation approach will ensure that we can manage transition to the next team for continuation of the project in the SDPS student portal. The potential impact on total budget is provided by project phase according to RUP utilizing best practices for student teams (Table 4.1).

Table 4.1 Budget Impact by Phase of *Health Quest* CDSS Project with STEM Portal

Project phase	Narrative of deliverables reported to NASA via interactive SDPS/K-12portal
Initialization	Marketing includes showing team accomplishments and relationship of *Health Quest* system to the Digital Astronaut Project, Human Research Program, and ISS as the project develops in phases. Transparent online reporting of student roles assigned in each phase (Project manager, chief architect, designers, analysts, etc.) for K-12 understanding, including teaching software engineering concepts and tools to student teams involved, supervising development of *Health Quest* Project during RUP phases, managing development of K-12 student portal online, facilitating SDPS support for local student paper, managing IAV Center environment
Inception (RUP I)	CDSS Vision document, IHMC Concept Maps, Research, FMEA, Gantt Chart/progress reports, SWEBOK/PMBOK review, Power point presentations, internal website portal, team roles expansion from design to implementation
Elaboration (RUP II)	Application Architecture/Information Architecture/System Architecture, SRS-IEEE 830, SDD-1016, PMP-1058, QFD, PRA, FTA, TRIZ, Gantt Chart/progress reports, UML/SysML/UMLS, Power point presentations, external website portal K-12
Construction (RUP III)	CDSS *Health Quest* Project Code and internal/external portal finalization, team implementation role assignments (Programming, testing, integration, etc.) Gantt Chart/progress reports, Power point presentations
Transition (RUP IV)	Maintenance, SDPS documentation, Gantt Chart/progress reports, Power point presentations
Deployment	*Health Quest* Project finalization for CDSS and STEM portal prototype, project documentation, team results, STEM K-12 impact, and its relationship to the NASA Human Research Program to attract further support and resources from STEM, SDPS, IPFW, NASA and other stakeholders

NASA SMART Objectives Reporting

Every semester, reporting of results can be accomplished by concept maps on the Specific, Measureable, Attainable, Relevant, and Time-sensitive (SMART) goals aligned with NASA Objective 2.3 (Curricular Support Resources to Educate and Engage), focusing on NASA Education Outcome 1.1 and 1.2 (1st choice) [21]: (1) Specific goal of a teamwork initiative is achieved by attracting a group of talented university students for RUP and STEM implementation (2) Measurable goal of industrial standards is achieved by applying the detailed syllabus of the multi-semester senior design course (3) Attainable goal of intellectual empowerment is achieved using the SDPS STEM K-12 portal as a multi-disciplinary platform for idea cross-pollination and online mentorship (4) Relevant goal of increasing diverse computing enrollment is achieved since all types of STEM students can participate in module development (5) Time-sensitive goal of semester completion is achieved by meeting specific benchmarks specified by IEEE 1058 project management plan. These SMART objectives are achieved by building cross-disciplinary awareness among students, engaging STEM students in K-12 with experiential projects accessible online, involving SDPS for ongoing STEM resources, supporting student paper activity, inviting under-represented students to K-12 STEM portal/CDSS peripheral work, and teaching students software engineering concepts, principles, and tools according to prevailing industry standards.

Cyber-Physical Systems Design Environment

The Information Analytics and Visualization Center of Excellence at IPFW provides an excellent new facility for educational and training purposes in this emerging field of Cyber-physical systems applied to medical informatics, biomedical engineering, and healthcare engineering [13].

Health Quest CDSS as a CPS Entity

Cyber-physical systems involve the tight conjoining of software and systems elements with respect to dynamic component demands that require attention to timing concerns that can impact performance characteristics of concurrent, distributed, and synchronous systems. Students can be introduced to design methodologies such as Concurrent Object Modeling and Architectural Design Method (COMET) [22] for UML. CPS design concerns, such as sensors and actuators, can also be designed using SysML so that both hardware and software are specified at the same time. For example, the software developed for the *Health Quest* CDSS system needs to be designed with CPS principles for advanced embedded systems in mind. These types of systems require various hardware interfaces, e.g. sensors for data collection from the patient and actuators that respond automatically to the decisions made by the AI modules of the CDSS. This requires CPS analysis of the design process for the *Health Quest* CDSS, which is another activity that will be introduced in the STEM component of the project. The CDSS will then be able to make real-time decisions and recommendations based on artificial intelligence logic applied to the information flow from the patient.

SDPS Student Paper Collaboration

Student teams from other organization at universities interested in CPS development can participate. They can collaborate with the student teams at IPFW. This would require proper setup of social media and modular technology to support the distance education plan. Hence, a network of SDPS student papers can contribute modules to the *Health Quest* CDSS project core architecture as they form teams for collaboration. This approach provides a plan for national (and international) expansion as more student teams are added to the SDPS web portal online that promotes the Software Engineering Society (SES) [4]. As more student teams contribute modules to the *Health Quest* CDSS architecture utilizing concept maps and other methods, the project outcome becomes more robust. As a result, the system capability increases, impacting all three areas of Research, Outreach, and K-12 STEM education.

IPFW Information Analytics and Visualization Center

The new Information Analytics and Visualization Center (IAV) [23] can provide further support for student teams that wish to utilize advanced multimedia technology for CPS design visualization. The IAV Center was established in June 2010 with grant funds in the amount of $500,000 provided by *The Talent Initiative*, *Lilly Endowment Inc.* One of the eight labs is the Healthcare Visual Analytics Lab, which can be supported by other labs focusing on information visualization, intelligent systems, knowledge discovery and data mining, networking and security, scientific computation, semantic computing, and software engineering. The student teams have access to the following equipment, including a two-wall Cave Automatic Virtual Environments (CAVE) system composed of the following hardware:

- Cluster computer with 20 nodes, 160 cores
- SGI high computing graphics workstation
- Devices for wireless and sensor network
- Immersive 3D Vision Systems with tracking devices

Software Engineering Approach Guiding CDSS Development

Software engineering and project management are taught every year to senior design and graduate students utilizing projects as experiential case studies. In one project, the focus for the semester was demonstrating skills in software engineering and software project management with a case study (Project SESnet), which exercised skills in developing, integrating, documenting, and managing the modules for a website with various functionalities applying appropriate information technology. The course was designed to provide students with experience in task management essential and critical to the software industry. The same course syllabus can be used to educate and train students in software engineering so they can design a CDSS with cyberphysical specifications.

Table 4.2 NASA SMART goals showing *Health Quest* CDSS project input and output

Logic table: NASA goals	Inputs	Activities	Outputs	Outcomes	Outcome Measures
2.3 Curricular support resources (educate and engage) outcome 1.1/1.2 SMART goals Teamwork, Standards, intellectual empowerment, diverse enrollment, and semester completion	IPFW lab students K-12 students IAV lab INSGC funding SDPS student paper	R&D Medical Guidance System STEM outreach via SDPS student paper, mentoring online, Project Q&A module design/code proposals	Multiple (e.g. 4) teams of 5 IPFW students Each student mentors online 1–10 STEM students in K-12 Multiple CDSS designs and specifications/ coding for ISS	Outcome 1.1/1.2 Up to 200 students in STEM impacted/ semester More enrollment in computing and IAV R&D/NASA interest generated STEM e-learning support developed with virtual collaboration tools	Number of students impacted Quality of students measured by test score improvement to qualify for IAV Center/ NASA R&D work Surveys indicating increased interest in STEM careers Number of follow-up spinoff grants and papers

Table 4.3 Helpful websites used throughout CDSS development

PMI: http://marketplace.pmi.org Managing and Leading Software Projects: http://www.computer.org/portal/web/book_extras/fairley_software_projects and www.12207.com
Sommerville textbook: http://www.comp.lancs.ac.uk/computing/resources/IanS/SE8/index.html
UML and related papers: http://www.uml.org/
SWEBOK and IEEE industry standards: http://www.computer.org/portal/web/swebok
Concept map tool download: http://cmap.ihmc.us/download/
Visio UML/SysML stencil download: http://softwarestencils.com/uml/index.html
Axiomatic Design tool and related papers: http://www.axiomaticdesign.com/technology/papers.asp
Microsoft alliance (Visio, MS Project tools): http://msdn05.e-academy.com/purduefw_ece
Virtual collaboration tool: https://signup.37signals.com/basecamp/Free/signup/new
Quality printing and PDF conversion: http://www.cutepdf.com/
Joomla content management system (CMS): http://www.joomla.org/
IEEE standards and corporations: http://standards.ieee.org/develop/corpchan/mbrs1.html

Approach to Teach Software Engineering in Context of CPS

Appropriate textbooks and important references introduced students to fundamental concepts needed for understanding industry direction and practice (Table 4.2). Key reference links were provided in advance, in addition to periodic announcements in the Blackboard learning management system. By the end of the semester, each team was instructed to prepare for submission the following deliverables for the case study: an attractive team binder, CD e-documentation of all project and individual work in binder, and an online concept map with relevant attachments in RUP format that can be used to present to employers. Each student prepared an individual concept map also using Cmaptools that was linked to the main project Cmap containing all documentation for the project in progress. A detailed project description was provided to guide the student development according to established industry standards, e.g. IEEE 1058 for the project management plan (PMP), IEEE 830 for the software requirements specification (SRS), and IEEE 1016 for the software design description (SDD). The Project Management Body of Knowledge (PMBOK) and Software Engineering Body of Knowledge (SWEBOK), in addition to the systems engineering standards were applied as needed (Table 4.3).

RUP Phases of Development that can be Adapted to CDSS Design

For project SESnet, the RUP phases followed with SWEBOK standards can be adapted to software engineering of a CDSS in context of a cyber-physical system. During the RUP Inception Phase a formal vision document was prepared and various technologies were downloaded and setup for collaboration. Other documents and technologies were acquired and utilized in other phases throughout the semester, continuing with the Elaboration, Construction, and Transition phases. A concept map was used for organization, documentation, version control, presentations, and efficient file sharing.

The application architecture identified key modules for development and scoping which was referenced and updated throughout all the phases. The modular approach to web development started with an application architecture that organized the web platform into nine separate modules for development by the nine graduate students. Modules were individually tested after development and during integration. Scalability is achieved, since additional modules can be added at a later time with reconfigurable options, as more students volunteer to develop Project SESnet during the summer and beyond.

Throughout the project a Gantt chart using MS Project kept track of progress for assigned tasks based on the Project Management Plan (PMP) prepared according to standard IEEE 1058. Basecamp collaboration software was utilized for teamwork between classes, along with tools for expedient file sharing, such as www.dropbox.com. Joomla, Magento, and eFront and other content management system technologies were tested and integrated into the main Joomla site requiring authentication. Students participated in weekly meetings to present their integrated approach, while announcements of required documentation, assignments, and project work were posted online in Blackboard, which is the e-learning management system environment utilized at IPFW. Students developed a website and slide presentation for each module at the end of each RUP phase to report their progress, including describing any challenges encountered, problems solved, and plans made for the next phase.

Functional requirements of the various modules were assigned to each student who then utilized various tools, including, for example, Acclaro DFSS for dynamically capturing the information architecture using an axiomatic design approach, after the overall application architecture was established. A design matrix was generated with functional requirements that could be hierarchically decomposed for analysis, as needed. Nonfunctional requirements, such as performance needs for the system, were developed using Quality Function Deployment (QFD). Risk management was done by utilizing a design structure matrix (DSM) and Failure Mode and Effects Analysis (FMEA) techniques, which can be streamlined using the Acclaro tool for axiomatic design. Then UML and SysML are used for detailed design according to the analysis produced during the Elaboration Phase.

Following the Project Management Plan (PMP) as a guiding document (based on IEEE 1058), the project deadlines were established, assigned, and managed for various assigned tasks using a Gantt chart. The functional and nonfunctional requirements were archived in the software requirements specification (SRS) according to IEEE 830 standard by the systems engineer in the group managing the industrial documentation. Visio UML stencil download was utilized for the application architecture. The Application architecture, Information architecture, system architecture, and UML/SysML diagrams were archived according to the

IEEE 1016-2009 standard. Concept map technology provided by the Institute of Human Machine Cognition (IHMC) was utilized (Cmaptools) for version control and overall mapping of the project according to RUP phases. Tools such as these simplified record keeping (e.g., project work as well as homework) for the instructor, the team leader, and the individual members. This approach made it possible to educate students on PMBOK and SWEBOK theory using RUP and axiomatic design approach and support tools, while conforming to industry best practices for the production of a professional web platform.

During the Transition Phase, a duplicate staging site with identical modules was planned, allowing for the module testing without affecting progress of the main production site in development. In the IEEE 1016-2009 standard, each object oriented UML class structure was documented that depicted static and dynamic diagrams for modeling the case study based on the application and information architecture. Risk mitigation techniques were utilized (e.g. DSM, FMEA). Each student also managed his/her own Cmap with all assignments and project documentation provided as attachments according to the RUP phases.

Final Project Submission for CDSS

The final project submission includes (i) hardcopy binder of all project work completed for semester (ii) electronic copies of all work completed on CD (iii) electronic copies organized and displayed online using a concept map in HTML and CMap format, including all versions of documentation. Primary items in the Notebook Binder/CD/Cmap should contain: Table of contents with page numbers, overview of project, final version prints of documents (e.g. SRS/IEEE 830, PMP/IEEE 1058, SDD/IEEE 1016, Acclaro DFSS design matrix including FR/DP decomposition and other architectural views, Visio, Gantt, research, slides, optional software tests and coding), Cmap/slides (10 Slides/month, total 40-50 slides/Each team member can contribute to the total slide number.), exams, conclusion, references, and appendix (if needed). The following final items (including all versions) are required at minimum in the CD. The binder contains the final versions only. All the following items can be viewed from the team website:

1. Cover page and Table of Contents (including Concept map in HTML and Cmaptools format)
2. Brief Project Proposal and Research
3. Personal skills/interests sheets
4. Vision document
5. Architecture (all types in SDD document)
   a. Application architecture
   b. Information architecture
   c. System architecture
   d. UML architecture (structure diagrams with behavior diagrams)

6. SRS with top-level FR list from App Arch (IEEE 830 format)
7. Axiomatic design tool screenshots for any features used
    a. Design Matrix—FR/DP
    b. DSM—DP/DP
    c. FMEA
    d. QFD
8. Progress reports (in MS Word, table format, weekly from each member)
9. SWEBOK technical reviews KA-1 thru 11
10. PMP (IEEE 1058 format)
11. Gantt chart (comprehensive)
12. All slides
13. SDD (IEEE 1016 format)
14. Individual work (e.g. Exams I & II, HW, etc.)
15. UML (in the SDD document)
16. Appendix (Anything else stated in your PMP deliverables table, e.g. feasibility)
17. Key References, in any convenient format
18. Acknowledgements (optional)
19. Conclusion
20. Future work

Conclusion

We proposed a university student team led *Health Quest* project that develops a clinical decision support system (CDSS) with interactive STEM online portal (K-12) as an extension to the NASA Digital Astronaut Project in context of a Cyber-physical system. This medical guidance system will be built by both graduate and undergraduate students, who can provide guidance/mentorship to K-12 students online throughout all development phases. The Information Analytics and Visualization (IAV) Center at IPFW provides an excellent new environment to build a CDSS that will prepare students for projects relevant to the NASA Human Research Program with support from contacts working on the Society for Design and Process Science (SDPS) [4].

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