

COLLABORATIVE EDUCATION: BUILDING A SKILLED SOFTWARE VERIFICATION AND VALIDATION USER COMMUNITY

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Abstract

Software quality is a crucial issue in Software engineering. As software has become ubiquitous, software products have become critical. This poses a multitude of problems in the software industry, as there is generally a lack of knowledge of Software Verification and Validation (V&V) benefits and also there is a significant shortage of adequately trained V&V practitioners. This paper describes the outlines of a research study that focuses on bridging these supply and demand and knowledge and training gaps in V&V education. Research outcomes both in terms of domain-specific research as well as pedagogical impact are presented. The basic project objectives are to improve software education at the undergraduate level and enhance on-the-job professional training, thereby increasing the pool of professionals with V&V knowledge and skills. The existing V&V course at the Author's institution is critically examined with a view to enhance and modularize selected topics, and improve delivery strategies by incorporating academic research findings and industry best practices. The cogent modules and strategies being developed in this work will be shared among project participants and disseminated to other institutions through multiple channels. Students and practitioners will be equipped with fundamental theoretical knowledge and invaluable hands-on-experiences that will

measurably increase their ability to contribute to the industry.

Background and Rationale

This project, funded by the National Science Foundation – Transforming Undergraduate Education in Science, Technology, Engineering and Mathematics (NSF-TUES) grant, has objectives to transform a required course in Software V&V offered to Software Engineering students at the author's University and disseminate it to the academic and professional communities. Existing course contents are being critically examined by a team of faculty and software development practitioners for the purpose of enhancing and modularizing the three credit semester long course using the ADDIE (Analysis, Design, Develop, Implement, and Evaluate) model for instructional design. The improved modules will be developed as mini learning workshops and will be initially delivered at seven universities and deployed by four organizations for on-the-job training. Based upon an assessment of the learning achieved in each delivery mode, the modules will be finalized and packaged for use by additional institutions interested in using the new courseware. In addition, the course modules and assessment reports will be made available through a courseware repository and conferences/publications, and professional societies (ex. National Science Digital Library –

NSDL, American Society for Engineering Education – ASEE, Association of Computing Machinery – ACM). The end result is expected to improve product and process quality levels throughout the software development community, resulting in a larger and more skilled software V&V user community.

The rationale for this project is significant. The Standish Group has categorized software projects as successful, challenged, or failed. Successful projects are defined as those completed on time and on budget, and with all features and functions as originally specified [1]. For the year 2011 the Standish Group's CHAOS report identified only 37% of software projects as successful [2]. While this is an improvement over previous years, it is still very low. However, much of the improvement can be attributed to implementing standards and practices, one of them being Independent Verification & Validation. [3]

Even after many years of developmental activities, software companies continue to spend considerable time and resources, directly and indirectly, dealing with issues of software quality [4]. Specific projects that fail can have a significant impact on many daily personal and business decisions. In October 2013 the US federal government rolled out a failed version of the universal health care website "HealthCare.gov" at a massive cost of \$330 million and counting [5]. Also in October 2013, Toyota was found guilty of causing death due to unintended acceleration, the root-cause being "a systematic software malfunction in the Main CPU" [6, 7].

There are many reasons why software fails, as is shown in the fishbone (alternatively known as the cause and effect diagram) given in Figure 1. This diagram depicts critical issues in the 4P's (People, Project, Product and Process) of effective project management that contribute to software failures. Poor software performance can be traced to a lack of courseware that inhibits both effective academic and on-the-job training. Software quality and software project

success rates indicate that V&V is not adequately practiced by the industry. In general, industry has not institutionalized V&V best practices and also lacks practitioners who have practical understanding of V&V topics. High quality software is achieved if software verification and validation activities are integrated into all phases of the software development life cycle (SDLC). For the \$549.3 billion (revenue) software industry [8] effective software verification activities will ensure that software development conforms to the desired specifications based on all the assumptions made. Validation activities are performed only after the software is developed to determine if the software correctly executes customer requirements.

Research Objectives

This project is designed to address V&V related root causes of software failure depicted in Figure 1. First, the improved courseware will be appropriate for delivery in undergraduate education programs, thereby improving the skill and knowledge level of graduates who will enter the software development profession. Second, the courseware will be packaged in discrete modules so that the project results can be used for in-house training programs that will improve the skills and knowledge levels of current software practitioners. Finally, the courseware will be developed and tested through the efforts of a team of university and industry partners creating a V&V community which can champion and promote expanded institutionalization of V&V best practices.

This V&V research is student focused and will contribute to knowledge about STEM education. The work will transform the existing undergraduate V&V course at the Author's institution (ENGR3400 – Software Verification and Validation). The proposed course enhancements and subsequent content modularization will respond to the National Research Council's (NRC) challenge "to deliver effective undergraduate education in STEM disciplines," namely answering the challenge of

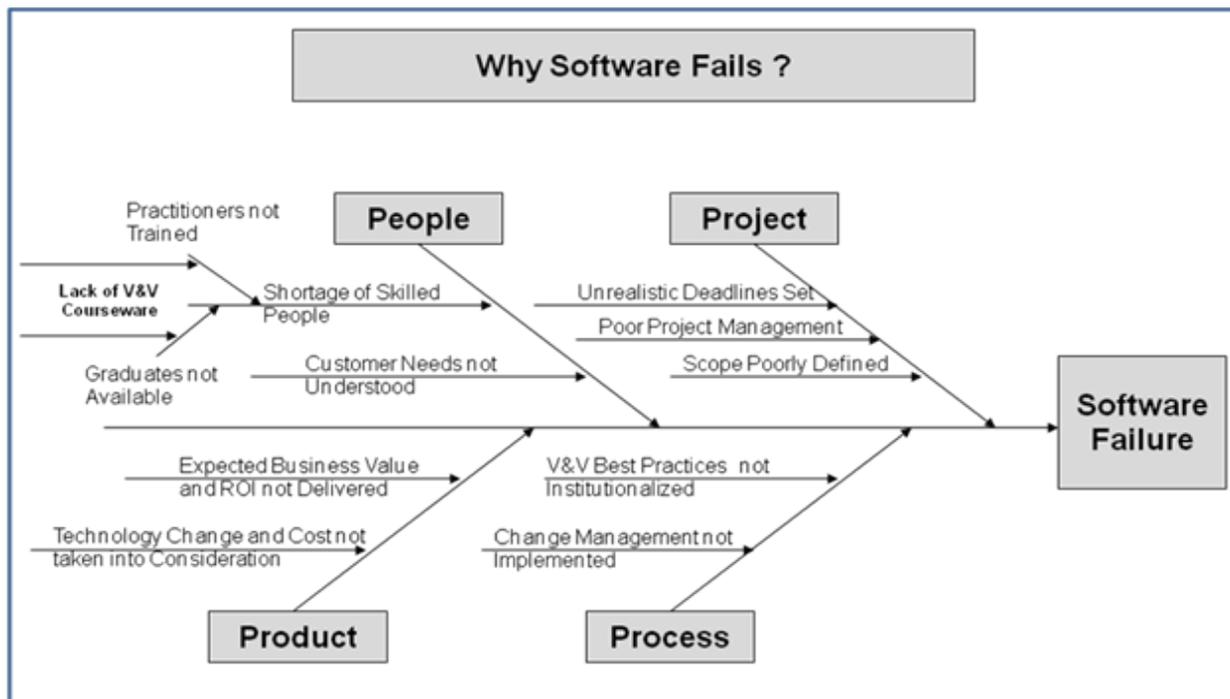


Figure 1: Why Software Fails?

providing engaging laboratory, classroom, and field experiences through improved communication skills, applied knowledge of methods and tools, and research exposure that will improve the practice of software engineering. Course enhancement will be guided by academic research and industry best practices and focus on four specific V&V topics: *requirements engineering*, *reviews*, *configuration management*, and *testing*. V&V related documentation will be an important component in each of these topics. Enhancement activities will involve assessing the current state of specific modules with academic partners, understanding industry requirements, developing course modules to address inadequacies using a design framework, and assessing the course materials and delivery for further revision and improvement. This modularization approach will also permit other participating universities to incorporate V&V course material into their own course curriculum.

V&V Research will support fundamental skills highly sought by employers' viz. *communication skills*, *applied knowledge of*

methods, *applied knowledge of tools*, and *research exposure*. Engaged laboratory exercises, collaborative classroom learning, and field experiences focusing on these key skill areas will drive the course enhancement. A compelling sequence of V&V topics will be delivered through mini learning workshops that will emphasize engaging learning activities and minimize lectures. The outcomes of the project are also expected to fill the V&V training void for industry professionals by providing materials to supplement existing on-the-job mentoring and training. By modularizing the course enhancements and making them available to industry partners the project expands the concept of "Student Focus" to include practitioners as well as undergraduate students. A strong academia-industry partnership is the key to the success of reaching these project objectives, and therefore *focus groups* comprising academic and industry partners have been formed for each of the four V&V skill areas listed above. They will work jointly to develop course modules that could be deployed for industry-based education applications.

Academic Research Outcomes

The goal of this project is to enhance and transform a Software V&V course into a series of mini learning workshops by incorporating academic research and industry best practices through an academia-industry partnership. This endeavor is intended to boost V&V awareness and increase skilled V&V practitioners so as to improve product and process quality levels throughout the software development community, resulting in a larger and better skilled software V&V user community.

The research work will lead to three beneficial outcomes:

- i. The most direct and obvious outcome will accrue to the students who are exposed to the enhanced course materials. They will gain improved knowledge and skills pertaining to software V&V. Over time, this supply of more knowledgeable practitioners will elevate the general V&V knowledge and skill level of the profession.
- ii. A second outcome, resulting from the collaboration of several universities and industry partners, will be an expansion of teaching and learning opportunities focused on software V&V.
- iii. The final outcome expected from this project is the development of a sustainable V&V “community” involving multiple universities and industries.

This project, scheduled for completion in August 2016, targets both undergraduate students and practicing software developers. Academic-industry partnership is important for achieving the project outcomes. The author’s university is collaborating with two categories of academic partners: *Development Academic Partners* (Virginia State University - a HBCU partner and Milwaukee School of Engineering) and *Implementation Academic Partners* Embry-Riddle Aeronautical University, Montana Tech,

University of Michigan, Virginia State University, Fairfield University, Milwaukee School of Engineering, ORT Braude College, Israel). These academic partners offer one or more bachelor degrees in Software Engineering, Computer Science, Computer Engineering, and Electrical Engineering. These partners also share a strong desire to strengthen their programs. The Author’s university is also collaborating with four industry partners that are either large software companies or companies with large software development activities. These partners are: Eaton Electrical Corporation, ServiceLink, PNC Bank, and JDA Software Group. Their areas of expertise are in mortgage, intelligent pricing and revenue management. For the research work, which is conducted through consultation and collaboration with these industry partners, these partners are expected to contribute in the following activities:

- Critically review and identify knowledge gaps in V&V courseware,
- Assist in developing course modules,
- Deliver expert lecture sessions to undergraduate students at partner universities if requested,
- Deliver training programs to industry practitioners,
- Assess student learning.

By involving multiple universities and industries it is hoped that the project will lead to the creation of a STEM V&V educational community. To ensure uniform curriculum development the project will take into consideration suggestions made in the IEEE/ACM, Curriculum Guidelines for Undergraduate Degree Programs in Software Engineering [9].

Finally, it is planned that the research output from this work will be made available to the general community via the National Science

Digital Library (NSDL), a NSF recommended centralized repository. NSDL which is widely available is the nation's online portal for education and research on learning in Science, Technology, Engineering, and Mathematics.

Pedagogical Significance

The proposed research is expected to enhance and enrich software V&V learning experiences for the students by adopting new methods of presenting the subject matter. The teaching materials created through this project will focus on practical understanding of V&V topics such as *requirements engineering, reviews, configuration management, and testing*. The resulting course materials will supplant their theoretical understanding by learning knowledge applications consisting of *case-studies, role-plays (exercises, videos), hands-on exercises, and expert lecture sessions (real time and/or pre-recorded videos)*. Provisions will be made for continued improvement of the courseware as well as for implementing partners to supplement existing course materials.

The pedagogical approach is strengthened by incorporating new instructional strategies to enhance knowledge retention in STEM education by promoting student involvement in the teaching - learning process. The strategy includes delivering a compelling sequence of V&V topics through mini learning workshops that will focus more on engaging learning activities and less on lectures. The instructional strategy will focus on student learning and will be adopted by instructors both at university and industrial facilities. The effectiveness of the pedagogical outcomes will be assessed at several institutions. As the project advances, additional faculty members from other universities/colleges will be invited to participate. To ensure adequate understanding of delivery strategies and assessment methodologies all implementing partners including industry partners will be invited to attend a two-day workshop at the Author's institution on a future date.

It is recognized that the evidence of improved knowledge and skills pertaining to V&V, improved V&V teaching and learning opportunities, and growth of the V&V community spanning industry and academia, are essential to the success of this project. The monitoring and evaluation plans for these outcomes will be designed to accommodate the varying expectations for each area. For the purpose of grading, appraising, and judging, student learning evaluations will be systematically carried out using a combination of instruments. Academic partners/instructors, and industry partners/instructors will be involved in evaluation and assessment activities. A team of two external evaluators will consult with focus groups in developing necessary questionnaires and instruments, to perform formative and summative evaluations.

Development of Teaching Tools

To support continued learning, development, and knowledge transfer, a Learning Management System (LMS) approach will be used to develop the enhanced course contents. In the scope of this research, the focus will be on instructor-led courses. For ease of adaptation, each module will be of 25 minutes duration, and depending on the subject area, some modules will have multiple parts delivered in multiple sessions. Each module will develop contents to meet its learning objectives. The contents will provide theoretical understanding supplemented by learning materials in the form of *case-studies, role-plays (videos and exercises), hands-on exercises, and expert-lecture sessions (real time and/or video)*. As workshops are vehicles by which a student learns the "know how" of performing, the materials developed through this project will be delivered in the form of mini workshops. Each module will also have a review section consisting of multiple-choice questions to assess student learning. Supplemental materials will contain case studies, role play videos, hands on activities, and expert lectures.

Case Studies

A set of V&V related case-studies drawn from industry experiences will be presented to the students. Case-studies will examine such content as legal issues in software, software consumer protection, and requirements from the customers' perspectives. A more exhaustive list of case-studies will be prepared by the focus groups. Students will analyze the case-studies in teams and discuss team views in class.

Role Play Videos

Currently, there is one commonly used role-play video on formal inspection that was developed by the Software Engineering Institute (SEI) in 1991. As this video is more than 20 years old and no other videos of this type have been found, there is a need to develop more videos capturing V&V activities in today's software development environment. The project will develop professional role-play videos, totaling about 30 minutes, in the following V&V activities: requirement elicitation (5 scenarios each 1.5 minutes in duration), code inspection (6 scenarios each 1.5 minutes in duration), walkthrough (5 scenarios each 1.5 minutes in duration), and budget request (3 scenarios each 1.5 minutes in duration). This list of topics will be reviewed by the focus groups. Industry partners who have addressed these topics and processes will be requested to provide a written scenario or a video tape of their in-house activity.

Video Specialists and students from the Author's University's Media and Arts department will provide preliminary support for writing the scripts, taping the scenes and editing the videos. However, as the production of these videos is an important project activity, professional script writers, taping crews, and editors will also be contracted so as to produce professional quality videos. Members from the Author's University's Theater Club, PIs, and partners will participate in the development of the videos. The Media and Arts department will work with the PI for the supervision and the

audio/video quality. Videos will be approved by the focus groups and assessed by the implementing partners.

Hands on Exercises

Hands-on-exercises will be enhanced to teach V&V processes, methods, and tools. These exercises will focus on, but not be limited to, the following: the requirements elicitation process, software testing, and expert lectures.

Students will be given an industry software requirement problem and asked to carry out the entire requirement development process that will involve elicitation, analysis, specification, and validation. For the elicitation process, mock sessions will be conducted. Role-play videos will be used to strengthen students' understanding of this process. Students will be required to use flow charts, structured English, state diagrams, case diagrams, and/or truth tables to reduce ambiguity when preparing a Software Requirement Specification (SRS) document. IEEE Std **830-1998** (IEEE Recommended Practice for Software Requirements Specifications) will be used to document the SRS. Students will also complete an exercise on requirements refinement. The exercise will require students to itemize requirements into a list of separate sentences and then classify these requirements as input conditions, expected results, and design constraint requirements.

Students will also use Basis Path Testing to perform White Box Testing. Testing will be based on Cyclomatic Complexity (software metric that provides a quantitative measure of the logical complexity of a program). Students will also be exposed to Control Structure Testing. For Black Box Testing, students will develop a test plan, create test cases, execute test cases, and submit a test report. An application software project completed by undergraduate students in a prerequisite course (ex. at Author's University: ENGR3410: Fundamentals of Software Engineering) could be tested using these processes. Students will

also be exposed to platform testing.

Students will be exposed to industry standards such as ISO 9001, IEEE software engineering standards, CMMI (Capability Maturity Model Integration), and IEEE/EIA12207 in the context of V&V. The standards will be made available for reference both in on-line and hard copy formats. Students will prepare all assignments according to the IEEE software engineering standards.

Expert Lectures

In the context of the existing V&V course, industrial partners, alumni, and in-house IT professionals have delivered expert lecture sessions at the Author's University. In 2011 lectures titled "Applying the inspection process in interface development." and "Testing web applications before placing in production – the case of a course registration system" were delivered by subject matter experts. To enhance this knowledge-sharing, a list of additional topics and experts will be suggested by focus groups. With permission from these identified experts, their presentations will be video recorded and made available for this project through the course repository.

Educational Enrichment

The enhanced course will be offered thrice during the project period. This delivery format will ensure course materials are further enhanced using experiences from the first and second deliveries (Spring 2014 and 2015). After each delivery of the course, summative evaluations from students, instructors and trainers will be analyzed and the course reviewed before the next delivery. A week-by-week course delivery plan for lectures and workshops will be developed. For certain workshops students will be taken to partner industry facilities, where industrial partners will deliver the course modules. This approach will enable students to observe real-world applications of concepts. In addition, industry partners will also deliver certain contents as

expert guest lecturers at the Author's university.

Course modules will allow students to gain experience in the following four key skill areas:

- **Communication Skills:** Multiple activities will be carried out to enhance students' communication skills. Sessions will begin with a class discussion on what was accomplished in prior sessions. Students will interactively participate in this collaborative review exercise. To have a better understanding of real work environments, students will participate in role plays and sample role-play videos will be used to encourage discussions to understand what is expected of the roles. During the final-examination week the students will give project presentations. Students will be made aware of the importance of professional presentations and will be assessed on their content knowledge and their communication of that expertise.
- **Applied Knowledge of Methods:** Mini learning workshops will be used to translate theory to practice. Case-studies, role-plays (videos and exercises), and expert lecture sessions will enforce further understanding of V&V methods. Videos developed from this project will be used for role-play analysis. Formal inspection meetings will be conducted and students will be assigned to play different roles (*moderator, author, recorder, reader, and inspector*). The expert lecture sessions planned in the course delivery will focus on V&V processes and methods. Hearing from people "*who have been there and done that*" makes it easier for students to understand and appreciate the critical importance of V&V in the workplace.
- **Applied Knowledge of Tools:** Mini learning workshops will expose students to commonly used V&V tools. For example, students will make use of an open source version control system for configuration

management exercises, and a defect management tool for defect management exercises.

- **Research Exposure:** Research activities will be carried out in three ways. The first will involve discussions on short case-studies. Students will read the case-studies, discuss within their team and then discuss with the class. The second research activity involves the study of research papers. The students will analyze five research papers and answer questions related to the paper. The third activity will involve understanding of industry standards. SE standards for V&V will be analyzed and discussed.

This project is expected to improve the knowledge and skills of both undergraduate students and industry practitioners in a measurable way.

Summary

Software quality is a crucial issue due to industry's general lack of knowledge of Verification and Validation (V&V) benefits and the shortage of V&V practitioners. This project intends to improve software education at the undergraduate level and enhance on-the-job professional training, thereby increasing the pool of professionals with V&V knowledge and skills. The project team consists of an academia-industry collaboration involving seven distinguished academic programs and four industry partners. At this time the project team is critically examining the existing V&V course at the Author's University, enhancing and modularizing selected topics, and improving delivery strategies by incorporating academic research findings and industry best practices. The cogent modules and strategies developed will be assessed, evaluated, and shared among project participants and disseminated to other institutions through NSF supported centralized repository (NSDL), conferences, publications, professional societies, and websites. Through the materials developed

students and practitioners will be equipped with fundamental theoretical knowledge and invaluable hands-on-experiences that will measurably increase their ability to contribute to the industry.

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Biographical Information

Dr. Sushil Acharya joined RMU in Spring 2005 after serving 15 years in the Software Industry. With US Airways, he was responsible for creating a conceptual design for a Data Warehouse which would integrate the different data servers the company used. With i2 Technologies he led the work on i2's Data Mining product "Knowledge Discover Framework" and at CEERD (Thailand) he was the product manager of three energy software products (MEDEE-S/ENV, EFOM/ENV and DBA-VOID) which were/are used in Asian and European countries by both governmental and non-governmental organizations. He has a M. Eng. in Computer Technology and a D. Eng. in Computer Science and Information Management with a concentration in knowledge discovery, both from the Asian Institute of Technology in Thailand. His teaching involvement and research interests are in the area of Software Engineering education, Software Verification & Validation, Data Mining, Neural Networks, and Enterprise Resource Planning. He is a member of Nepal Engineering Association, ASEE, and ACM. He has published several papers in peer reviewed journals and co-authored a textbook. In 2013 he received a National Science Foundation (NSF) Grant for developing course materials through an industry-academia partnership in the area of Software Verification and Validation.

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