Session T1: V&V Education in Academia

Session T1 leaders:

Co-Chairs: **Virginia Dobey** (DMSO) & **David Luginbuhl** (Western Carolina U.)

T1 Materials in Foundations '02 proceedings:

Paper

The Role of Educational Institutions in Verification and Validation Preparation (12 pp)

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Slides (may contain back-up materials and notes)

Teaching System Modeling, Simulation and Validation (26 slides) [T1B_desel in both pdf and ppt formats]

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The Role of Academic Institutions in Validation and Verification Education (41 slides) [T1B_gray in both pdf and ppt formats]

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Participants in this session are listed at the end of the Discussion Synopsis.

Discussion Synopsis (to provide perspective on papers & briefings identified above).

The session was opened by a challenge to consider the question, "What is the skill set with respect to V&V that the new graduate should have to become a V&V professional?" It was immediately decided that whatever that skill set might be, it would have to be applicable in the cross-disciplinary environment of M&S. This raised immediately the issue of what the technical societies say about V&V. An informal poll of the participants turned up the following views:

- The ACM Computer Science Curriculum recommendations include a course on software "Validation," and electives on Formal Methods and Reliability.
- No V&V (or V&V-like) courses in the equivalent American Physics Society or American Mathematical curriculum documents.
- The Society for Industrial and Applied Mathematics has a newly formed special interest group in computational science and engineering.

The consensus was that V&V needs to be reflected in actual university curricula and that the technical societies need to be encouraged to support V&V.

Some "must know" objectives are presented. Modeling and simulation practitioners must know where to look for hidden/ implied/aggregated assumptions in code. They must know where to look for places where inaccurate, imprecise collected data are presented as highly precise, highly accurate values but potentially introduce errors that, when accumulated, may prove very significant. They must know where in the system we should focus efforts on improvement of accuracy; for example, clean up very imprecise data collection instead of pushing the algorithms from second order to third order. Practitioners must know how to recognize that we are using a linear algorithm in one place, a third order equation in another, and merging the data with the assumption that the result has the accuracy and precision of the third order equation calculation.

Basics

What are the core skills needed for V&V? We need to ensure that V&V is not limited to a single discipline such as "computer science", "mathematics" or "physics". V&V must span disciplines. While this point was well made in the presentations, the group emphasized this repeatedly. If we had to summarize our discussion and recommendations into one point it would be that **"V&V EDUCATION MUST BE MULTI-DISCIPLINARY!"**

V&V transcends modeling. Students should learn what can be verified and what can't be verified.

Specifications are a model of the requirements. This emphasizes the modeling relationship and the fact that the abstracted version of almost anything serves as a model. We immediately move, at the earliest stages of a development, into the concept of representing the real world. Our students must understand that modeling begins with validating the requirements: the specifications must be the right capture of the requirements and the conceptual model must be the right capture of the specifications. These are concurrent processes with any verification work (often computer science-based) that must also occur.

V&V education must include introduction to uncertainty, errors, and error control. Knowledge of statistics is important and knowledge of *applied* statistics is critical. This is why students must learn a stand-alone discipline, like meteorology, aeronautical engineering, or biology, in order to properly learn validation. Validation is a concept that takes form only when it is applied to the real world. Hence, a student must be challenged to apply her/his knowledge of statistics, mathematics, and computing — which provide the conceptual foundation for verification — in courses such as "Applied Statistics in Meteorology" and "Applied Mathematics", to provide the conceptual foundation for validation.

What is the role of education versus training? It is important that we focus on the foundational concepts for V&V and not necessarily "marketable skills." Otherwise, we run the danger of universities becoming trade schools. There is a definite place for on-the-job training and continuing professional development in V&V after graduation (Session T8 addresses this aspect). This was brought up in the V&V education in industry session: one speaker noted that he doesn't want graduates with degrees in V&V or even M&S – he can handle much of the specific training in these areas using professional development courses.

Teams and communication skills are crucial to education and success in industry.
Cross-pollination should be made an academic goal.

A View from Europe

We were fortunate to have a participant from Germany who could articulate a European viewpoint.
A comment was made that European computer science emphasizes formal methods throughout the undergraduate curriculum. Europeans want complete programmer. But they must ask, "Can we teach everything?" German students are good programmers but tend to have problems in communicating with users. The European formal methods view is that verification is proofs of correctness and testing is not the main technique. Validation is a model-building issue. The discussion nicely captured the divergence between verification and validation — Europeans teach verification. But how do they do validation? The students don't have the background and perspective to bridge the chasm between the technician and the user. That continues to be a significant problem in U.S. Government development projects. Program managers tend to know the technical aspects or the user requirements, but generally not both.

Pedagogical Issues

Should we look at what drives the life cycle for clues to what and how to verify and validate?

It was immediately noted that the various development paradigms such as waterfall and spiral do not map onto academic disciplines. It is even harder to map V&V onto curricula.
The catch phrase "right system" requires the developer to set the context for 'right'.
The first programming course in Germany students are introduced to Hoare triples and is specification based.
Levels for integrating V&V: at the module level, at the course level, at the program level
A problem was noted that we should try to get V&V ideas out without necessarily pushing the words "verification" and "validation".
V&V in an inquiry based coursed would work.

You can't teach everything. One way to get V&V into the curriculum is to prioritize the subjects that must be taught. We moved away from the perspective that V&V can be taught in stand-alone courses and toward the perspective that V&V requires knowledge of many important concepts, most of which are taught in other courses. The only specifically-V&V course might be seminars that integrate all of the concepts taught elsewhere and demonstrates their application in the "real world."

Inquiry Based Education. Computation and V&V are skills that must have application. Students must learn to question. (Original comment was "CS, V&V are tools…." David objected to using the word *tool* in this context. My translation tries to catch sense.) The idea conveyed was that CS and V&V have value in their APPLICATIONS. We can teach the concepts—and SHOULD—as stand-alone concepts and associated techniques, but we NEED to teach students how to APPLY them to knowledge of the real world. This ties back to the idea that we can teach verification and its associated skill-set, but validation must be taught in the context of applied statistics, applied mathematics, and other applications to real-world situations.

Some direct comments on pedagogical approaches:
"Validation driven design modification" as a design/modification approach for simulation design.
"Focusing on errors in modeling would also go a long way to support V&V thinking."
"V&V thinking" is a variant of "systems thinking".

Issues

There is a general need to have a fresh viewpoint. From the earliest days, computer development has equated "good" with "fast". The High Performance Computing Initiative seems to equate "V&V" with "the code works." In the 1990s, physics drove system development with constant demands for more FLOP performance. ASCI still has need for massively parallel/distributed systems.
The question was raised concerning the taxonomy "verification and validation" and for that matter the education hierarchy "K-12".
A problem was noted concerning the lack of standards in undergraduate education in science, engineering, and mathematics.
We need to develop a "modeling emphasis" instead of a software engineering emphasis. The difference is caused by the focus on applying software engineering skills to compare the engineered product to the real world —validation — as compared to focusing on using those same skills to improve the engineered product.
Formal methods are slowly evolving in curricula in the United States but this is quite behind the focus on formal methods in Europe. The new IEEE/ACM curriculum barely mentions formal methods and the curriculum is notably lighter weight scientifically and mathematically than current curricula.

ROI ideas

One of the authors introduced the idea of evaluating curricula with respect to return on investment (ROI). An important question focuses on how a university quantifies ROI. Who determines it? How do you measure it?
It is necessary for universities and the business community to work together. The Government represents the customer…who sets the requirements for the end product/ deliverable. Businesses employ people who can satisfy those requirements and provide the end product (V&V services) to the Government. The universities must be able to supply the conceptual (education and not training) skill set that businesses require to develop the V&V practitioner.

The group EMPHASIZED the importance of feedback to universities to help determine ROI. **Unless the business community provides solid, meaningful feedback** to universities about their graduates (NOT just in terms of initial employment of graduates) and those graduates' ability to apply the conceptual foundations obtained in school, **universities will continue to teach what THEY think businesses (and their customers) want**. What is meaningful feedback? University administrators value letters about the quality of their graduates from businesses (on letterhead). These letters should be directed to the University president. Other feedback might be statistics on the ability of, and time required for, graduates to progress from having V&V education to achieving "V&V practitioner" status (see next section).

Another type of feedback manifests itself in employment advertising. While many businesses would not specifically advertise for V&V experts or even V&V practitioners, language describing desired V&V skills should be included if we hope to convince academia that it is worthwhile to educate students in V&V concepts. Ideally, job ads in the Washington Post and the New York Times would consistently state such requirements—if students (one set of university customers) see that employers WANT these skills and will pay well for them, then they will establish one side of the demand to which universities respond. Business feedback based on graduates' ability to support client requirements establishes the other side of the demand to which universities respond.

Implementation Issues

Question: how do you get feedback to universities on the quality of graduates? If we are to ask university cooperation in developing V&V practitioners, feedback on their efforts is ESSENTIAL. A good way is to work through a professional society. The group raised a question on the status of the "V&V practitioner" certification effort that was proposed a couple of years ago. They believed that this concept should be reexamined and moved forward.)
Suggestion: We need a consortium of academics and industrial partners for accreditation. Would this be like a professional engineering accreditation?
What is the status of the DMSO certification of V&V professionals?
How about summer courses? We need to work with employers to help the transition into OJT. (Group T8 needs to address this issue—what skills will the employer build on top of the knowledge base that a graduate brings from academia?)
There is a clear need to define career paths. The professional community needs to understand that new academic emphases happen in academia when there are documented job opportunities that can be demonstrated to administrations and legislators. In general, academics teach what the students request and students request courses that will get them jobs. So — if you want to influence academia, then advertise for V&V skills in employment literature.

Certification

How do you convince academics that V&V is important, but not necessarily requiring a new course in scientific validation? One teaches verification skills. One applies these skills in validation. Instead of trying to teach validation, we need to have students develop a reasonable proficiency in another academic area—and then complete our V&V education by APPLYING verification and validation skills to that academic area.

We are not teaching "how to DO" V&V in meteorology, acoustics, etc.—but rather, "how to approach" V&V by applying our V&V concepts to their academic interest area. We must not teach a checklist—but need to teach students where to look for potential errors, what

questions to ask, and how to identify hidden assumptions in the translation of physical laws from mathematical equations to computer algorithms, and so forth.
The security community has an interesting model: NSA-certified programs in Computer Security, such as those at FSU and James Madison (and others)

Is it important to distinguish verification technology from validation technology? Perhaps we need a V&V education certification — met through education, and a follow-on V&V practitioner certification, which converts the education certification to a practitioner certification after a given length of employment/training in applying their V&V education. This program of certification can find many models in the military services.

Curricular Recommendations

Middle School

1. Fundamental algebra. It is very important that students understand concepts like $(a + b)^2$ does not equal $a^2 + b^2$.
2. Basic logic and proofs including formalisms such as modus ponens and modus tollens.
3. Machine model of computing and principles of operation, including number systems.
4. Emphasize verification as a natural adjunct to mathematics. For example, that the verification of division is multiplication
5. Examples of great learning activities (learning objectives → tasks) to support the inclusion of V&V concepts in middle school curricula may be found at http://www.shodor.org/interactivate

High School

1. Algorithms as representations of the real world.
2. Pre-calculus.
3. Advanced algebra including combinatorics.
4. Inductive proof
5. Geometry with emphasis on deductive proof. Return to Euclid's *Elements* Students need to learn how to identify new concepts and how these concepts are integrated into "the next step."
6. Introduction to statistics. This might be combined with economics or government — ways to use and abuse statistics, proper ways of interpreting statistics. Interpreting mean, standard error, linear statistics and non-linear statistics, etc.
7. Computation and computer principles. We discussed this more of an emphasis on "how a computer works" and 1GL/2GL, such as assembler and FORTRAN. Many of the group members believed that if you taught students how the computer works and how these earlier languages actually interacted with the computer controls — of moving numbers from register to register, of integer and float storage, of obtaining information from input devices and sending it to output devices — that they would be far better prepared to understand simulations and algorithms in the way that we need them to view embedded assumptions,

computer storage impacts on precision and accuracy, and wrong presentation of an imprecise number as a far more precise number than collection technology can support.

8. Modeling. This clearly can be done in the science sequence, but also in economics, government, and the social sciences, too. Numerical prediction.
9. Approximation and error. In particular, interaction of terms and introduction of errors because terms interact. Numeric computing in context of modeling and problem solving
10. Based on discussions in the T8 session and group comments, teaming and communication skills must be emphasized in the undergraduate program.

Baccalaureate

1. Calculus through ordinary and partial differential equations with emphasis on "epsilon-delta" proofs.
2. Discrete mathematics, especially through graph theory and linear algebra.
3. First order logic.
4. Numerical methods especially errors and error estimation.
5. Probability/Statistics applied in science.
6. Applied mathematics in science using numerical methods.
7. 2 or 3 courses in science or engineering with emphasis on numerical prediction in the particular scientific/engineering discipline. This requires the student to have enough "real-world" knowledge against which to compare mathematical models of that same real world, because it is only in this type of comparison that we can effectively teach validation.

For the most part, engineering and science students receive this training; however, in today's crowded curricula, there is a danger of a lack of breadth in the engineering and scientific education. Computer science students do not get the numerical methods and applied mathematics courses and often lack significant scientific and engineering experience.

General Recommendations

The foundations of modeling, simulation, and V&V are laid in middle and high schools. According to psychological research, modeling is the foundation of all problem solving. There needs to be more emphasis that knowledge is based on validated models. There was general consensus that there should not be a degree in verification and validation. A V&V practitioner must have domain knowledge as well as V&V methodologies. The question was asked, "Are we not doing ourselves a disservice by the different taxonomies?" The group was not sure.

All papers presented at Foundations '02 should be checked for information relevant to curricular development.

This group's recommendations should be conjoined with the T8 group's recommendations to ensure that the skill recommendations support the full range of practitioner needs.

We close with a question. “What are facilitating educational objectives?” The answer lies in broadening M&S from its current narrowly defined view.

T1 Session Participants (8)

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