Inserting Science and Technology Into the Systems Acquisition Process

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ABSTRACT

One of the most pressing challenges facing managers of basic science, applied research and advanced technology is inserting the knowledge, components and products produced in Science and Technology (S&T) programs into acquisition programs of record. Over the past decade, the US Navy and Marine Corps have had several documented successes in merging basic S&T products into the DoD acquisition process. In this paper, the Office of Naval Research's Virtual Technologies and Environments (VIRTE) program is presented as a successful case study for how scientific exploration and advanced technology development can be integrated with the systems acquisition process to provide today's Warfighter with validated, effective training tools. Over six years, the VIRTE program focused on using a modified form of the Instructional System Design (ISD) process combined with management oversight techniques such as Virtual Product Teams and Intermediate Feasibility Experiments, to develop Virtual Environment based solutions to target a range of US Navy and Marine Corps training gaps. The process was adapted from elements of the DoDI 5000.2 Acquisition Management Framework, particularly those that deal with User Needs and Technology Opportunities at the Pre-Systems Acquisition stage. Along with a discussion of the methods and techniques used, this paper will also provide a detailed discussion of some of the more critical challenges faced by the program development team and suggest how and where lessons learned could be applied to future programs. Special emphasis is placed on developing measures for assessing program success. In particular, these measures include: the number of products successfully transitioned to US Navy and Marine Corps programs of records; performance enhancement based assessments; and measures of cost/benefit. These transition successes, lessons learned and processes developed are extensible across the spectrum of S&T projects and acquisition programs of record.

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INTRODUCTION

Why Modeling and Simulation?

Regardless of whether one's goal is to train a business person to more effectively conduct their trade, a commercial pilot to utilize cutting edge flight aids or a Marine to conduct the art of war, a high price is typically attached to delivering effective training. This is not necessarily a direct result of the pursuit of profit. Often times, the context within which training is best offered is simply expensive. Consider for example, the price of operating a basic military vehicle, be it land, air or sea; the per hour cost can often reach into the thousands of dollars per vehicle. Factoring in the need to 'train as we fight', which demands multiple vehicles, across multiple domains, yields a per hour cost that easily pushes into the tens of thousands of dollars. Add the requirement of practicing in live fire situations, ones which could lead to loss of vehicle (or life) and the associated price can exceed millions of dollars.

This cost has led to a strong requirement to seek alternative methods to achieve effective training solutions. Over the past decade, modeling and simulation tools have emerged as practical components for effective training. In fact, one such tool, virtual environments (VE), has increasingly been offered as a potential solution for training challenges (Davies, 2002). In many ways VE systems offer the ideal training environment. Their fundamental applications are primarily software driven (Cohn, Helmick, Meyers, & Burns, 2000); the footprint for the hardware supporting these applications is shrinking at a quasi exponential rate (Moore's law; Appenzeller, 2000; Blachford, 2004; Buck et al., 2004), albeit with some limitations (Stanney & Zyda, 2002); and the cost associated with producing these systems is likewise shrinking. Finally, errors made during training in a VE do not have 'structural' impact, (e.g., a damaged virtual aircraft will not result in any additional cost; a mistake made in distinguishing between a virtual friend or foe will not result in actual bodily injury). Hence, dangerous or challenging training events can be practiced using this technology while simultaneously offering the potential of notable cost savings.

Quantifying Cost

While it can be difficult to quantify the benefits and costs associated with each training system component, a useful point of comparison is the cost associated with the basic operation of a platform during a training exercise. As Figure 1 suggests, the costs associated with operating a real vehicle are on the order of 19 times those associated with operating a virtual reality simulation of that vehicle.

	Operational Hour Cost	Simulated Hour Cost	Simulator Cost Ratio
FA-18A	$ 3955	$ 217	18/1
SH-60B	$ 1724	$ 118	15/1
LCAC	$ 3000	$ 300	10/1
M-1 TANK	$ 144 (Per Mile)	$ 4.34	33/1
	Average	Ratio	19/1

Figure 1. Comparison of costs of operating a vehicle vs a simulation of that vehicle (NAWCTSD, 2002).

The challenge with making such comparisons is that no single measure captures the entire set of factors contributing to 'cost.' Cost can include all of the research and development efforts conducted up to the point of beginning mass production; test and evaluation; maintenance; and the tradeoffs between time required to train in the VE vs. time required to train in the actual craft (Wickens & Hollands, 2000). Clearly, this makes the decision of how to develop, integrate and evaluate the utility of VE training tools a complex one. Complicating matters more, within the Department of Defense Guidelines, many of these questions are meant to be addressed during the Science and Technology (S&T) stage of acquisition. Yet there has remained a distinct lack of dialogue between the training S&T community and the training system design and acquisition community (Cannon-Bowers, Tannenbaum, Salas & Converse, 1991). Accurate cost estimates must be derived through a collaborative process including S&T and acquisition stakeholders.

The Challenge Defined

Undoubtedly, this problem has multiple etiologies, such as the lack of time, money or personnel to develop (for each VE system) a comprehensive model linking learning science principles with systems design (Learning Federation, 2003). Nevertheless, a more fundamental weakness in this chain is the relative failure of the two communities, S&T and Acquisition, to develop a shared, common language for exchanging information. On the one hand, the S&T community must understand the requirements set forth by the Acquisition community and tailor their research efforts such that they support these requirements while mitigating risk. This may mean sacrificing the statistical power of experiments that could be maximized in a lab setting using college students performing simple tasks on abstractions of the actual system. Or it may mean shifting focus from scientific theory to application. On the other hand, the Acquisition community must understand the demands of the rigors of science. This includes understanding that science typically does not produce simple answers to complex problems and that the inherent risk associated with testing new theories may mean that S&T insertion points on an Acquisition program's Plan of Action and Milestones and Work Breakdown Structure, typically used by systems engineers, may need to be flexible to enable insertion from the S&T process at multiple stages. However, without S&T, the Acquisition program incurs a greater risk in maintaining cost, schedule, and performance than if it considered including S&T as a risk mitigation.

It is this divide that the current paper seeks to bridge. As a case study, using the Virtual Technologies and Environments (VIRTE) program, an Office of Naval Research sponsored effort, this document will demonstrate one successful approach for inserting S&T principles and products into the systems development and acquisition process. The VIRTE program is ideally suited for this because it demonstrates a unique approach to blending elements from Modeling and Simulation, Human Factors, Experimental Psychology, and Systems Engineering in order to develop and transition validated training tools that are technologically sound and performance enhancing and that satisfy identified Warfighter training requirements. As will be seen, in addition to the various approaches for linking S&T with systems design and acquisition, one management tool in particular appears to have played a critical role in VIRTE's success, that is, the emphasis on continuous review to ensure satisfaction of customer requirements and to keep the customer informed of the S&T project's progress. In keeping with this theme of continuous review, a program health scorecard was developed. Factors assessed by this card include: 1) How can the Navy be sure the provided system is being utilized? 2) What metrics were developed to ensure that performance was enhanced through the use of the provided VE training solution? 3) What impact does this system have? 4) Since the VIRTE program is an S&T (6.1-6.3) research effort, how will its systems be mass produced in a cost effective fashion? This report card will be revisited at the end of this paper, in an effort to assess the program's relative success.

VIRTE'S APPROACH

Objectives

The overarching goal of the VIRTE program was to develop, validate and transition a series of VE based training tools to US Navy Marine Corps customers. This high level goal was achieved by focusing on four key principles, regardless of the particular system being developed:

1. Understand how to train warriors considering increasing complexity, information demands, and chaos by focusing research on an expanding operational domain.
2. Understand how to supplement and complement live and classroom training using virtual and wargaming simulations.
3. Achieve significant time and cost savings by eliminating software licensing fees.
4. Increase human performance by matching training technologies and strategies to requirements.

The Systems

In keeping with individual customer requirements, VIRTE was parsed into three stages: an Expeditionary Warfare (EW) stage, which transitioned various VE-based vehicle simulations; a Human Immersive Technologies (HIT) stage, which transitioned a series of infantry based VE training tools; and a Multi-platform Operational (Distributed and Asynchronous) Team Training Immersive Virtual Environment (MOT^{2}IVE), which transitioned a series of platforms for supporting Combined Arms exercises. The MOT^{2}IVE systems were developed that targeted training the Forward Observer (FO) and Forward Air Controller (FAC) within a networked battlespace involving other ground and air simulations.

The virtual component systems for the EW stage were based on operational requirements for operating specific vehicles. The Landing Craft Air Cushioned (LCAC) serves as a highly maneuverable hovercraft platform that can quickly move troops, vehicles and equipment from ship to shore. The Expeditionary Fighting Vehicle (EFV) acts as a highly defendable troop transport that can move quickly either in the water or on land. The MV-22 is intended to serve as an air platform for, among other things, rapid troop insertion. The corresponding VIRTE systems include: a Virtual Environment Landing Craft, Air Cushioned (VELCAC); a Virtual Environment Advanced Amphibious Assault Vehicle (VE AAAV); and a Virtual Environment Helicopter navigation training tool (VE Helo).

The virtual components for the HIT stage of VIRTE emphasized the ability to create realistic human-VE interactions, from the ability to move around naturally in a simulated dismounted environment to the ability to perform a series of complex, team-based activities such as building clearing. Unlike the EW stage, the parameters for supporting these 'natural' interactions could not be simply modeled after any real world correlate. This would require a reduction of every possible sensory cue to its most basic element and would be prohibitively costly. Instead, HIT focused on a holistic approach to providing trainees with the necessary information cues and interaction techniques, maximizing trainees' subjective perception of being immersed in a virtual world rather than the physical world one in which they are currently situated in (Stanney et al., 1998). This was done in several ways, from providing engaging training content to providing natural modes of interaction and movement control. EW and HIT S&T products directly linked to corresponding acquisition programs and have transitioned to their respective programs of record.

The virtual components for MOT^{2}IVE were much more far ranging, including Computer Generated Forces (CGF; using Joint Semi-Autonomous Forces scripts); M&S tools representing the FO/FAC positions, as well as depicting other vehicles such as the Amphibious Assault Vehicle, AH-1 Cobra Helicopters, AV-8B Harriers and transport aircraft; the US Army's Dismounted Infantry After Action Review System (DIVAARS) and various gateways to other real-time information sources to enable a mission rehearsal component. The components of MOT^{2}IVE have begun transitioning and will continue to transition to US Navy and Marine Corps Acquisition Program Offices following completion of user validation and training evaluation efforts.

The Naval Research Enterprise

In order to meld science with product, VIRTE emphasized the notion of the Naval Research Enterprise, the idea that S&T should be inextricably linked to the systems being developed. Thus, underlying the technical goals of Stage 1, was a theoretically-driven motivation to capture a validated process for rapidly prototyping these systems. The motivation for developing this Human Centric Development Model (HCDM) was to determine how to inform and bound technology solutions with Human Factors principles. The actual HCDM was validated through the development and transition of the VE systems. Similarly, in Stage 2, the motivation was to gain a deeper understanding of the relationship between technical fidelity and performance enhancement, leading to the development of a Fidelity Matrix. These principles were developed and validated in the systems being transitioned to the USMC. Finally, in Stage 3, the focus shifted towards determining how to embed instructional principles in the technologies being created throughout the VIRTE program, resulting in an Instructional Strategies Matrix (see Figure 2).

Linking an Acquisition Framework with Instructional System Design

The DoD Perspective

To a certain extent, the approach undertaken by VIRTE is derived from the Defense Acquisition Management Framework. DoDI 5000.2 (Department of Defense) outlines a process for managing acquisition programs, including elements that comprise S&T, and the methods for linking the results of S&T to System Acquisition (Figure 3). Understandably, this bi-directional 'conversation' is neither easy to establish nor straightforward to maintain. Rarely does a scientist in a lab have direct access to their Program Manager. Equally rarely, system developers typically do not have the chance to express their questions and concerns in such a way that the scientists would be able to develop testable hypotheses to address their concerns. This is as much a direct consequence of the sequential nature of programs as it is one of configuration management.

The Training Community Perspective

Within the training system community, these challenges have been tacitly recognized since the early 1970s, through the development of a set of methodologies known collectively as Instructional System Design (ISD; Dick, Carey, & Carey, 2001). A general model of ISD, taken loosely from Branson et al. (1975) and Clark (1995) is presented in Figure 4.

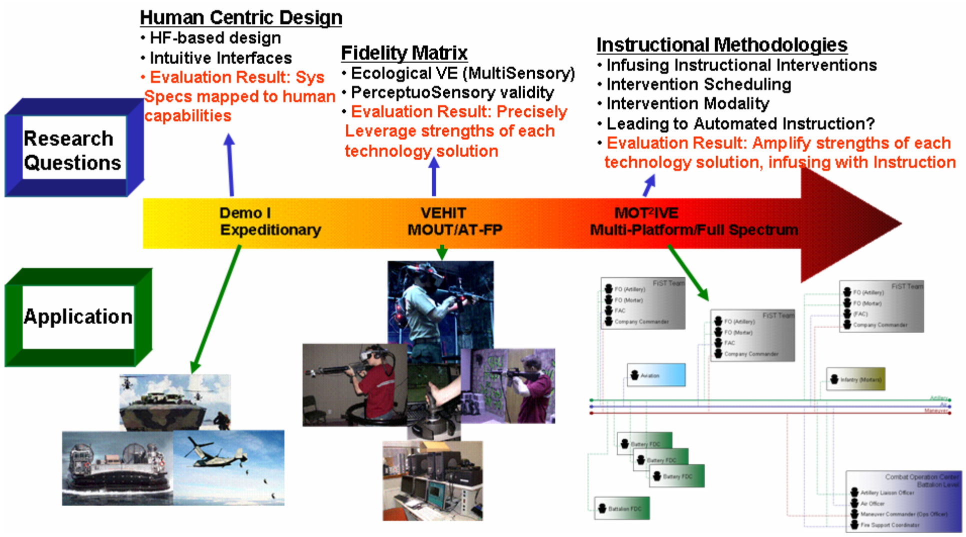

Figure 2. Research questions (top) linked to customer driven applications (bottom)

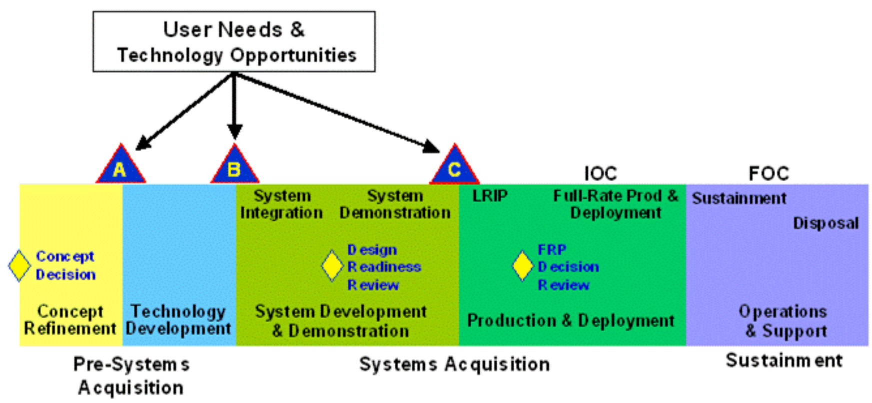

Figure 3. Defense Acquisition Management Framework. The process consists of 3 Activities: Pre-Systems Acquisition, Systems Acquisition, and Sustainment. S&T occurs during the first Activity Stage (Department of Defense, 2003). VIRTE is concerned primarily with the first two Activities.

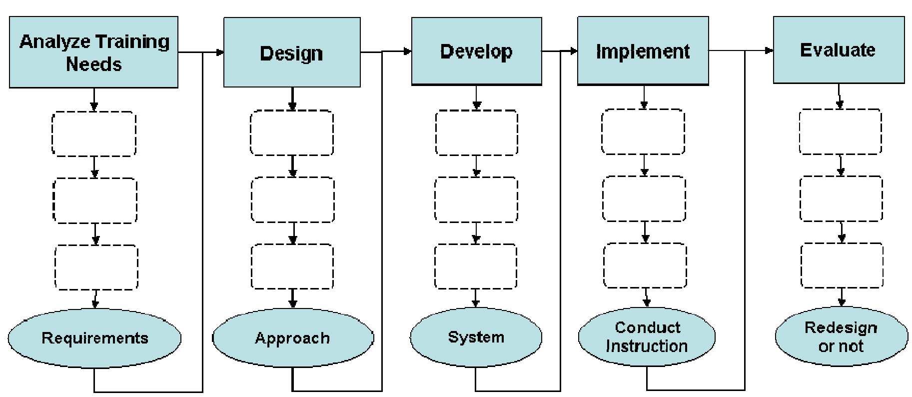

Figure 4. A generic Instructional Systems Design Framework, consisting of 5 separate phases, each with its own end product (ovals).

As with the DoDI 5000.2 framework, the entire process is theoretically sound but difficult to apply; the mechanics for moving through each stage and from stage to stage are ill defined. More often than not a given ISD model is exactingly domain specific, providing little ability to generalize across domains/tasks as well as providing little guidance for how to do so.

VIRTE's Contribution

Realizing these inherent limitations in both approaches, the VIRTE program has focused on finding a middle ground in ISD that is founded on general science theory (from cognitive/knowledge engineering to Usability Engineering/Human Factors to Education Science) and that directly pulls in elements from all three Activities defined in the Acquisition Framework model. Importantly, Wilson, Jonassen and Cole (1993) point out the single most problematic feature in the ISD model provided above: that it is essentially linear and unidirectional, in contrast to the 'ideal' ISD model, which would allow feedback within and between the Phases. Borrowing a page from the development of large scale systems (Whitten, Bentley & Barlow, 1989), VIRTE has effectively demonstrated an approach that non-linearizes ISD partly returning it to its antecedents, merging science with engineering throughout the Acquisition process.

This approach resulted, first and foremost, in a modified version of the typical ISD model (Figure 5). These changes, the most critical of which involved implementing an evaluation process at each phase, provided all members of the VIRTE program, including the customers, with multiple opportunities to gauge progress and make any necessary corrections.

A second modification to the S&T *status quo* involved the use of Virtual Product Teams (VPT; McMahon, 2001). The notion of a VPT is modeled after that of the more traditional Integrated Product Team (IPT), with the added flexibility of being able to sustain interactions between team members, across management levels. The elements of the VIRTE VPT included Scientists, engaged in the basic research efforts necessary to support system specification and evaluation; Engineers, engaged in system development; and Fleet customers, from whom requirements were continually obtained, defined and refined. A third difference implemented by VIRTE was the use of Technology Transition Agreements (TTAs). These documents were essentially agreements between all VPT members, which defined what systems would be delivered to which customers; with what capabilities; at what time; and with what level of validation. Finally, for each stage, the VIRTE program instituted a series of Intermediate Feasibility Experiments (IFE), at the rate of one per fiscal quarter. These IFEs were meant to provide the entire VIRTE team with program progress snapshots, with all members attending and providing updates, comments and criticisms. Before each IFE, entrance and exit criteria were established by all VPT members. Depending on the larger goals, these entrance and exit criteria could be as simple as (entrance criteria) 'all system components developed to a certain level independently' and (exit criteria) 'all system components successfully integrated and operational for 8 hours.'

THE RESULTS

As mentioned earlier, all stages of VIRTE followed a modified ISD model. In general, the approach taken began with up front analyses of training objectives, activities which correspond to the concept definition and user requirements stages of the Pre Systems Acquisition Activity Stage. This was followed by a set of Usability analyses (Nielson, 1993), the character of which was determined by the demographics of each system's user population. The Usability analyses directly supported the technology development phase of the Pre-Systems Acquisition. Additionally, the Systems Development and Demonstration phase of the Next Activity was supported as the prototype training system was subjected to full operational testing and training effectiveness evaluation. This provided a means for transitioning data and technologies from the Pre Systems Acquisition Activity Stage to the System Development and Demonstration phase of the Systems Acquisition Activity Stage. The following sections expand on this process for each stage of the VIRTE program.

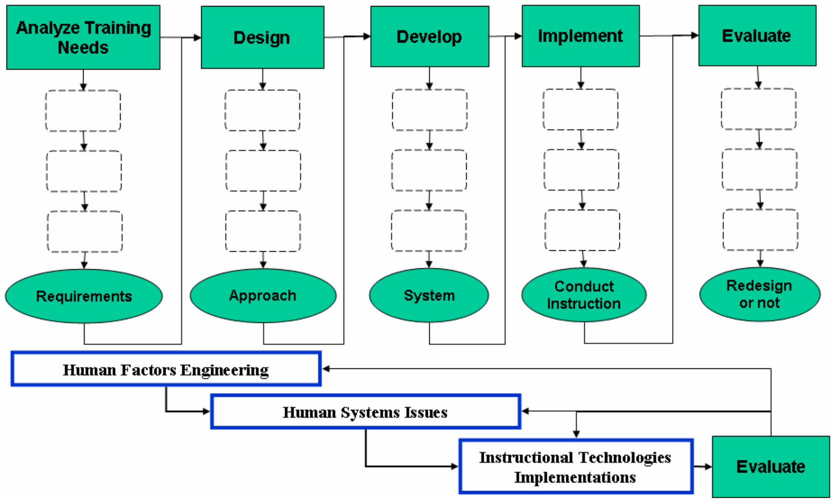

Figure 5. Modified ISD model implemented by VIRTE. The 5 phases are mapped onto VIRTE's 3 stages. A critical modification is the emphasis of evaluation following each stage.

VIRTE Expeditionary Warfare – Stage 1

The EW stage focused on developing an empirical model for designing, validating and transitioning specific VE systems to six different customers (see Table 1). Each of these customers required different levels of input from the model's components in order to meet defined requirements. As a result, in order to effectively deliver specific training systems on schedule and within budget, VIRTE S&T emphasized different aspects of research for each system. Critical results from this stage, in addition to the development of the actual VE systems, included advancing a method for determining where, in existing training curricula a particular VE system could most effectively be inserted; designing and testing a unique methodology for conducting knowledge elicitation in Operational settings; and modifying the accepted training transfer paradigm (c.f. Murdock, 1957) to ensure generalizability to the largest possible training audience. Various aspects of these efforts have been reported elsewhere (Muller, Cohn & Nicholson, 2003; Milham, Hale, et al, 2004; Cohn, Schmorrow et al., 2005; Schmorrow et al., 2006).

VIRTE Human Immersive Technologies – Stage 2

The HIT stage focused on developing a better understanding of the relationship between VE system component technology and degree of performance enhancement. In other words, it addressed the question of whether or not higher fidelity is worth the added cost, in terms of performance improvement. The systems under development for this effort transitioned to a single customer, the USMC Program Manager for Training Systems. In order to satisfy their requirements, one of which included developing a fidelity matrix to help Program Managers make informed System Acquisition decisions, the VIRTE program developed two completely different sets of VE tools, both of which are currently in transition to various USMC components. Studies conducted on these systems included exploring different types of user interfaces and techniques for enabling immersed trainees to perform manual actions, such as locomotion and object manipulation, in the VE; the impact of different types of visual displays on the performance of (simulated) room clearing tasks; and the effectiveness of including multi-modal sensory cues (haptics and spatialized audio) into the VE systems.

While each of these aspects was explored independently, a comprehensive training transfer study was also conducted, in which all these different technologies were integrated into one of two VE systems, a high end one, in which the very highest fidelity components were used, and a low end one, in which lower end fidelity components were used. Teams of trainees representing a range of skill sets (from Novices, pulled from University subject pools, through experts, comprised of USMC Infantry returning from tours of duty in Iraq) were then exposed to either one or the other of these two systems, and subsequently tested at an indoor MOUT facility to assess performance enhancement. These efforts have been documented elsewhere (Cohn, Whitton, Razzaque, & Brooks, 2004; Whitton et al., 2005; Fowlkes et al., 2005).

VIRTE Multi-platform Operational Team Training Immersive Virtual Environment – Stage 3

This stage's main goal was to develop a multipurpose, cross-platform, performance enhancement training tool set that targeted the individual, a single team, and teams of teams and that could be used for a range of training applications such as:

a) Pre-schoolhouse preparation
b) During schoolhouse training supplement
c) Sustainment training
d) Refresher training

Importantly, unlike the previous stages, which had specific training objectives embedded directly in the system, the systems being developed in this final stage were intended to have a broad instructional applicability. Thus, these VEs were designed from the start to be heavily grounded in validated Instructional Systems Design principles with evaluations occurring in both the lab and deployed settings by the end-user. Thus S&T efforts focused on determining how to provide instruction during training, what format to use when doing so, and when to do so, while systems development efforts focused on determining the underlying architecture for utilizing performance based measures and interventions to deliver this instruction.

Scorecard

Each stage of VIRTE established a unique set of performance metrics. These sets of measures contained variables that were subjective or objective; system-collected or observer collected; and, either fed back into the system to modify training protocols or utilized in some format as a feedback tool. At the same time, programmatic metrics were also developed, to enable the VIRTE management team to adequately assess progress and success. While many of these measures include the more commonly recognized cost, schedule and performance measures, this set of measures reflect a snapshot of program health. Performance on these measures is provided in Table 1 and discussed in the following sub-sections.

How do we know it is being used?

One of the greatest challenges in developing and transitioning S&T systems is ensuring that, once the program that generated them has ended (once the team members have essentially stopped interacting with the customers), they continue to be used. This challenge is particularly acute in those programs that transition S&T to larger efforts as the components or the knowledge developed by such S&T efforts may be lost in the shuffle of the larger program of record.

One way of assessing success is to determine if customers have, of their own initiative, continued to use and modify the technologies and purchase new systems. As Table 1 suggests, the products of VIRTE have demonstrated widespread utilization by Fleet customers.

Table 1. Assessment of VIRTE in terms of the program health scorecard

Question	How do we know it is being used?	What metrics demonstrate enhancing readiness?	How is training cycle being shrunk?	Plans to Productize
Stage I	1. VELCAC: PMS377 purchased for ACUs, continues to be employed for additional uses and we continue to interact and advise 2. VE HELO: At NPS, NAVAIR, HS-10, and Pendleton 3. VE EFV: Transition Platform Contractor for ACQ POR using system for insertion of embedded training concept	1. TEE data 2. Continued enhancements requested by customers 3. Spot-requests by customers for immediate use 4. FY07 Culminating Events • Integrated Field Experiment • Operational Field Testing • @ 29 Palms • @ Camp Lejune • @ Camp Pendleton	1. Supplement training 2. Provide mission rehearsal and sustainment training Capability 3. Seabasing / Deployable Training	Working with multiple Industry Partners using Open Source, and 0 licensing-fee software: Principal industry partners engaged: 1. Lockheed Martin 2. BMH 3. CHI 4. VRSONIC 6. Artis LLC 7. SwRI Gov't Partners: 1. CTTO VISIT 2. US Army
Stage II	1. 16 AAV TT Systems being procured; force wants more 2. MOUT system being used at Army NG testing US Marines from IOC and rotating back from theatre			
Stage III	1. USMC User testing 2. ACQ POR identified out year funding			
	Continued coordination with current and past customers	**Lab and field data + user acceptance**	**Supplement curricula, provide new opportunities**	**Bring them in on ground floor**

What metrics demonstrate enhancing readiness?
One of the greatest shortcomings of many acquisition programs is their failure to quantify the impact of their products on performance. VIRTE, through its modified ISD approach, which includes extensive training effectiveness evaluations (TEEs) with the end users, essentially makes this demonstration of utility a natural extension of the design process.

How is the training cycle being reduced?
While TEEs provide one way to assess system utility, it is not always the case that the capabilities of these systems are fully exploited. Although training systems may be provided to their customers with a demonstration of their effectiveness, the system's users may not be given clear guidance on how to integrate these tools into existing curricula. VIRTE has made a point of working with customers to not only assess training effectiveness, but to also provide users with a roadmap for integrating tools into their training syllabi.

Plans to productize
While the Defense Acquisition Management Framework (Figure 3) suggests a smooth transition of data and technologies from the Pre Systems Acquisition Activity Stage to the Systems Acquisition Activity Stage, this is rarely the case. To mitigate this risk, the VIRTE program ensured from the start that Industry Partners, capable of large scale production, were members of the VPT. Additional risk mitigation came from partnering with other service members, to both leverage existing data and technologies and to provide a means for cost sharing various development efforts.

CONCLUSIONS

A major challenge facing managers of S&T is how to transition their S&T products into Acquisition Programs of Record. ONR's VIRTE program was presented as a case study outlining how success was achieved in transitioning S&T into acquisition, providing today's Warfighter with validated, effective training tools that are still employed today. For future S&T programs to be successful at transition to acquisition, the following recommendations apply:

- Define the applied objectives of the S&T.
- Develop prototypes based on customer requirements.
- Consider the Naval Research Enterprise and link S&T to the prototype development.
- Adhere to the DoDI 5000.2 framework and integrate it with a relevant established S&T framework (in this case, ISD).
- Hold reviews and conduct frequent evaluations to provide acquisition customers the opportunity to gauge S&T progress and suggest corrections.
- Assemble Virtual Product Teams with scientist, engineer and Fleet/Force members.
- Through Technology Transition Agreements, document what S&T prototypes will be delivered to whom; what the capabilities of the prototypes will be; when the prototypes will be delivered; and what level of validation the prototypes will have.
- Hold Intermediate Feasibility Experiments (IFE) quarterly and define entrance and exit criteria for these.
- Develop a scorecard with measures for assessing an S&T program's success and score the program at least annually.

Although the recommendations presented here were developed as part of a specific effort, they were designed to be extensible across the spectrum of S&T projects and acquisition programs of record. It is our intention that to successfully impact the Warfighter through transition of S&T to acquisition, the recommendations presented here should be followed with adaptations and modifications for specific situations.

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REFERENCES

Appenzeller, T. (2000, May 1). The chemistry of computing: Computers made of molecule-size parts could build themselves. *US News and World Report.* [on-line] http://www.usnews.com/usnews/issue/000501/chips.htm.

Blachford, N. (2004). The future of computing part 4: The next generation. CS News: Exploring the Future of Computing [on-line]: http://www.osnews.com/story.php?news_id=6089

Branson, R.K., Rayner, G.T., Cox, J.L., Furman, J.P., King, FJ, & Hannum, W.H. (1975). *Interservice procedures for instructional systems development.* Fort Monroe, VA: U.S. Army Training and Doctrine Command.

Buck, I., Foley, T., Horn, D., Sugerman, J., Fatahalian, K., Houston, M., & Hanrahan, P. (2004). Brook for GPUs: Stream computing on graphics hardware. *Proceedings of SIGGRAPH 2004*. Los Angeles, California. August 8-12, 2004.

Cannon-Bowers, J.A., Tannenbaum, S.I., Salas, E., and Converse, S.A., 1991, Toward an integration of training theory and technique. *Human Factors,* **33**, 281-292.

Clark, Donald. 1995. *Big Dog's ISD Page.* Available at http://www.nwlink.com/~donclark/hrd/sat1.html#model (Accessed 2 April 2006).

Cohn, J.V., Helmick, J., Meyers, C. & Burns, J. (2000). Training-Transfer Guidelines for Virtual Environments (VE). Proceedings of *22^{nd} Annual Interservice/Industry Training, Simulation and Education Conference,* Orlando FL.

Cohn, J., Schmorrow, D., Nicholson, D., Muller, P., Stanney, K., & Milham, L. (2005). Trainee-Centric Design for Developing Military-Based Virtual Environment Training Systems. *Proceedings of Human Computer Interaction International 2005, Las Vegas, Nevada.*

Cohn, J., Whitton, M. Razzaque S. & Brooks, F. (2004). Information Presentation and Control Method Impact Performance on a Complex Virtual Locomotion Task. Proceedings of *48^{th} Annual Human Factors and Ergonomics Society Conference*, New Orleans, LA

Davies, R.C. (2002). Applications of system design using virtual environments. In K.M. Stanney (Ed.), *Handbook of Virtual Environments: Design, Implementation, and Applications* (pp. 1079-1100). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Department of Defense Instruction 5000.2 (2003), "Operation of the Defense Acquisition System," http://131.84.1.34/whs/directives/corres/pdf2/i50002p.pdf (Accessed 15 April 2006).

Dick, W., Carey, L. & Carey, J.O. (2001). The systematic design of instruction Addison Wesley, New York: NY

Fowlkes, J., Washburn, D., Eitelman, S., Daly, J., & Cohn, J. (2005). Use of Haptic Displays to Enhance Training in a Virtual Environment. *Proceedings of Human Computer Interaction International 2005, Las Vegas, Nevada*

The Learning Federation, 2003, Learning science and technology R&D roadmap. Available online at www.thelearningfederation.org (accessed 28 May 2006).

McMahon, P.E. (2001) Virtual Project Management, CRC Press, Boca Raton:FL

Milham, L., Hale, K., Stanney, K., Cohn, J., Darken, R., & Sullivan, J. (2004). When is VE training effective? A framework and two case studies. Proceedings of *48^{th} Annual Human Factors and Ergonomics Society Conference*, New Orleans, LA

Muller, P., Cohn, J.V., & Nicholson, D. (2003). Developing and Evaluating Advanced Technologies for Military Simulation and Training. Proceedings of *25^{th} Annual Interservice/Industry Training, Simulation and Education Conference*, Orlando, FL

Murdock, B. B. (1957). Transfer design and formulas. *Psychological Bulletin*, 54(4), 312-326.

Naval Air Warfare Center Training Systems Division (2002). Command Brief. Orlando, FL.

Nielsen, J. (1993). Usability engineering Academic Press, San Diego: CA

Schmorrow, D. Lyons, D., Lackey, S., Allen, R., Norman, K & Cohn, J. (2006). Virtual Reality in the Training Environment, In: D. Vincenzi and J. Wise (Eds): *Human Factors in Simulation (In Press).*

Stanney, K.M., Salvendy, G., Deisigner, J., DiZio, P., Ellis, S., Ellison, E., Fogleman, G., Gallimore, J., Hettinger, L., Kennedy, R., Lackner, J., Lawson, B., Maida, J., Mead, A., Mon-Williams, M., Newman, D., Piantanida, T., Reeves, L., Riedel, O., Singer, M., Stoffregen, T., Wann, J., Welch, R., Wilson, J., and Witmer, B. (1998). Aftereffects and sense of presence in virtual environments: Formulation of a research and development agenda. Report sponsored by the Life Sciences Division at NASA

Headquarters. *International Journal of Human-Computer Interaction*, 10(2), 135-187.

Whitten, J. L., Bentley, L. D., & Barlow, V. M. (1989). *Systems analysis and design models* (2nd ed.). Homewood IL: Irwin.

Whitton, M., Cohn, J., Feasel, J., Zimmons, P., Razzaque, S., Poulton, S., McLeod, B., Brooks, F., "Comparing VE Locomotion Interfaces," in *Proceedings of Virtual Reality 2005,* (Bonn, Germany March, 2005), 123-130, IEEE Computer Society.

Wickens, C.D. and Hollands, J.G. (2000) *Engineering psychology and human performance* (3rd edition). New Jersey: Prentice Hall.

Wilson, B.G., Jonassen, D.H., & Cole, P. (1993). Cognitive aproaches to instructional design. The ASTD hanbook of instructional technology, 21.1-21.22). New York: McGraw-Hill http://carbon.cudenver.edu/~bwilson/training.html (accessed 28 May 2006).