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SE Simulation Experience Design: Infrastructure, Process, and Application

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Abstract. The Systems Engineering Experience Accelerator (SEEA) is a new approach to developing the systems engineering and technical leadership workforce. The project is aimed at accelerating experience assimilation through immersive, simulated learning situations where learners solve realistic problems. A prototype of the technology infrastructure and experience content has been developed, piloted, and evaluated. While the prototype has proved useful, its ability to support a community of educators and developers is limited by the challenges in creating or changing experiences. This paper proposes an initial taxonomy of experience archetypes to help development and reuse of experiences, and describes the experience design and development process using the SEEA tool suite. This is followed by an application case study: an experience developed by the United Kingdom Ministry of Defence to accelerate the maturity of reliability engineers and their role in identifying and resolving safety issues.

Background

Systems engineering is a practical, experienced-based discipline where value is more related to the application of experience and the understanding of technical decisions than in applying specific techniques or tools. While such tools are important, without the domain experience to provide context and insight, the quality and usefulness of the results can be poor.

Traditionally, Systems Engineers (SEs) develop deep knowledge by working for extended periods of time with people from multiple domains, systems, subsystems and disciplines.

While a traditional model of education can teach the fundamental body of knowledge, it is not until this knowledge is put into practice in an integrated, real world environment that a systems engineer can develop the necessary insights and wisdom to become proficient. Systems engineering educators are struggling to meet the growing educational demands for a workforce able to solve problems driven by accelerating technology, rapidly evolving needs, and increasing systems complexity (Bagg 2003; Cox 2014; Davidz & Nightingale 2008; Hao 2015; Wade et al 2015; Wade & Turner, et al 2015). At the same time, there is a widening gap in industry between the need and the availability of systems engineering practitioners with the necessary experience to address these challenges (Squires, et al 2011).

SEs are more likely to be young with little experience, or, if they are more mature, required to work in new, unfamiliar domains. It may take years and many projects for a new systems engineer to encounter, consider, attempt to solve and see the results of implemented solutions. The type and depth of the learning experience is constrained by the type of projects and lifecycle phases available when transition begins. Mentoring and hands-on learning through successful and unsuccessful analyses and decisions are more effective, but are staff-intensive and thus costly.

The Systems Engineering Research Center's (SERC) Systems Engineering Experience Accelerator (EA) project has been addressing this problem through immersive, game-like experiences where a learner can encounter a variety of realistic situations and attempt to resolve them using their existing experience as well as "fail-fast" experimentation (Charette 2008).

Experience Accelerator Project

The Systems Engineering Experience Accelerator (SEEA) project was designed as a response to these critical needs and challenges. The project goals are to:

- assess the feasibility of an immersive, simulated learning approach for accelerating systems engineering competency development
- validate the ability of such an environment to create an experiential, emotional state in the learner
- determine if such an environment, coupled with reflective learning, effectively compresses learning time.

If the above goals are achieved, then the SEEA could significantly increase the experiential resources available to a systems engineer (SE) over time, and provide assimilation of the experiences at a higher rate as compared what would occur naturally on the job.

The Systems Engineering Experience Accelerator is a suite of software and manual tools that provides immersive problem-solving experiences to accelerate the competency of systems engineers. The suite consists of two major systems. The Experience Delivery System comprises the User (Learner) Interface client component, a server component that controls the experience, and a simulation and collection of artifacts and other data that provide information through the User Interface. The delivery system currently consists of a prototype experience in which the learner is chief engineer of an unmanned aerial system program (Wade et al. 2015). The Experience Construction System comprises tools that help develop experiences, including dialog construction, artifact development, experience scripting and phasing, and simulation development and tuning.

This paper is more concerned with the Experience Construction system. It includes custom built tools as well as COTS applications. The custom-built tools include:

- **Sim Builder -** Simulation model builder using libraries/templates
- **Sim Tuner** - Parameter tuner that automates the tuning of parameters to yield desired outputs via batch processing of different combinations of settings
- **Chart Designer** – Automates design of simulation output charts
- **Experience Builder** – Integrates the Phase and Event Editor, and the Artifact Integrator
- **Phase Editor** - GUI-based tool for phase, cycle and event specification, with code generation
- **Event Editor** - GUI or text-based tool to specify events and their triggers, with code generation

- **User Interface Editor** – GUI tool to support tailoring the user interface to the specific experience and simulation(s) involved
- **Artifact Integrator** - Application that allows designer to take artifact files, such as design documents and enter it into EA application with automatic recompilation and re-linking
- **Learning Assessor** - Assessment tool-suite that provides automated performance scoring and decision comparisons against proven baselines

ChatMapper® is a COTS non-linear dialogue development tool used to support conversations with non-player characters (NPCs). Work aids, primarily spreadsheets, have been developed. A website with access to the accelerator and tools, as well as information and support, is also under construction. Figure 1 shows how the tools relate to the various parts of the SEEA Architecture.

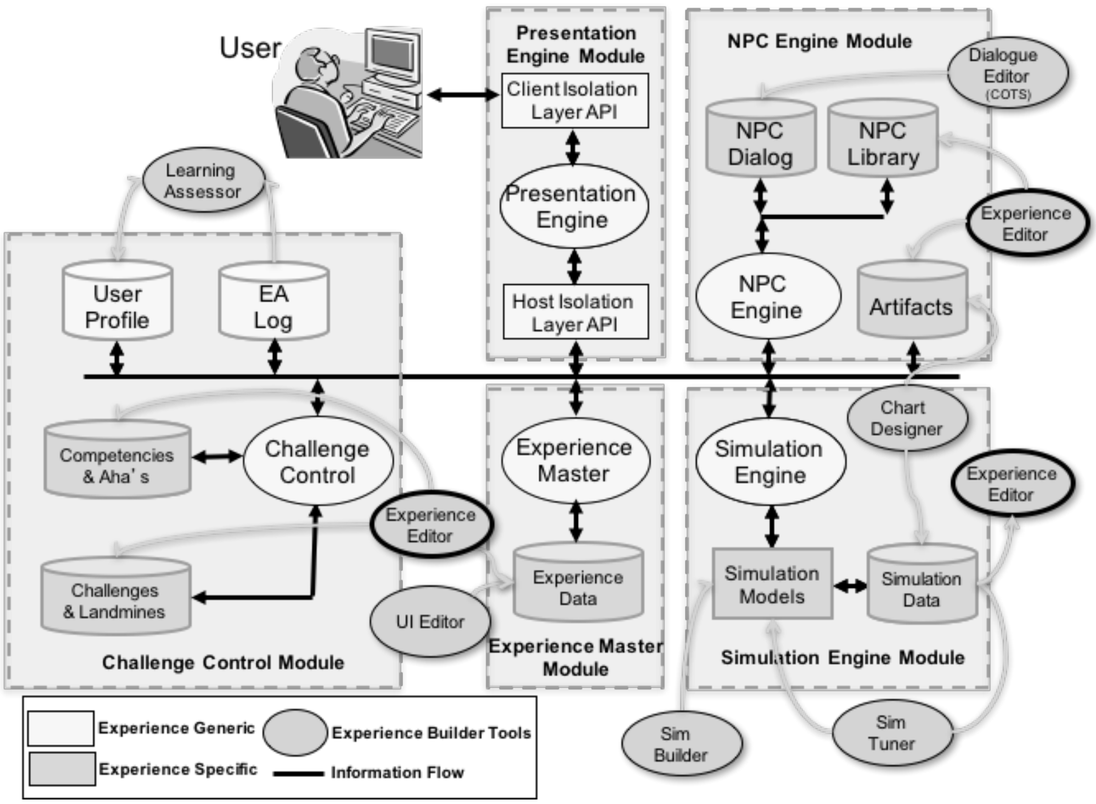

Figure 1. The SEEA Architecture showing where the tools are used

Learning Experiences Taxonomy

Learning Objectives. Educational objectives are a staple of most course and curriculum development. The objectives are usually stated as a form of knowledge, understanding, or skill that a learner will gain from a class, a course, or a lab. The following is a definition of a learning objective (Arreola & Aleamoni).

> *A learning objective is a statement of what students will be able to do when they have completed instruction. A learning objective has three major components:*
>
> 1. *A description of what the student will be able to do*
> 2. *The conditions under which the student will perform the task.*
> 3. *The criteria for evaluating student performance.*

In the Experience Accelerator, learning objectives play a similar role as they do in curriculum development. However, they are defined in terms of the specific environment and work experiences that are deemed by the organization to be critical to success. Rather than creating a complete description of an area of experience, the objectives are aimed at a specific skill or a critical situation where significant experience is particularly useful. This might be the case where there may not be effective heuristics or tools. For example, consider the complex intellectual task of making a significant technical decision based on data from multiple, diverse sources, of known and unknown accuracy, in an environment where the stakes are large in terms of finance, safety, or other factors. Living through such an experience may happen only a few times in a career. However, as the systems engineering environment deals with greater uncertainty and higher complexity, performing well in such a situation becomes more important. An EA experience designed with learning objectives tailored to this activity can provide a range of situations that learners can asynchronously enter without having to be on the right project, in the right place, at the right moment.

Learning Experience Types. Experiential learning can take many forms, but the EA's immersive aspects and simulator-based data generation are particularly appropriate for experiences with decision scenarios complicated by data, personality, and environmental issues. There are common factors that come into play in such cases, and an informal pattern description language is being developed to help experience developers identify the critical aspects of a scenario for the experience. While conceptually based on the categorizing of literary or theatrical plots, the current taxonomy is less an analytical construction, and more a reflection and organization of concepts and discoveries drawn from creating an experience. Table 1 shows the initial version of the pattern language, and an example of using the components to create a trade study experience pattern is provided in Table 2.

The EA team has also identified personality-related attributes in the literature that can be used to add human relationship complexity. In the included case study, these attributes played a very significant role in building the learner's experience.

Table 1. Pattern language components

Pattern components				
Learner Modes	**Learner Authority**	**Learning Objective**	**Associated Learner Skills**	**Associated Learner Activities**
Individual	Directive (do)	Recognize	Understand information	Monitor, measure, recognize, interpret
Collaborative	Responsive (recommend)	Define	Articulate a problem	Gather information, analyze, confirm, create
	Passive (observe)	Plan	Articulate possible solutions	Gather information, create, confirm, propose
		Choose	Decide on a solution	Structure, analyze, confer, select
		Act	Implement the solution	Communicate, advocate
		Evaluate	Determine if solution works	Monitor, measure, recognize, interpret

Table 2. Trade Study Pattern

Trade study: Problem is provided to learner who must identify alternatives, select one, advocate for it, and possibly evaluate results				
Learner Mode	**Learner Authority**	**Learning Objective**	**Associated Learner Skills**	**Associated Learner Activities**
Individual	Responsive	Plan	Articulate possible solutions	Gather info, analyze, create, confirm
		Choose	Decide on a solution	Structure, analyze, confer, select
		Act	Implement the solution	Communicate, advocate
		[Evaluate]	Determine if solution works	[Monitor, measure, recognize, interpret]

Experience Development Framework

This section establishes a framework for creating and applying immersive experience-based learning to systems engineers in development and acquisition organizations. The framework is primarily directed toward rapidly maturing new or relatively inexperienced systems engineers. It can also be used to support those who have a solid foundation in one or more domains, but are transitioning to a domain with only minimal understanding of the new environment. It builds on and amplifies the mentoring activities of normal technical management by providing new ways to identify, characterize, and transfer experiences from mentor to mentee. It may also be adapted to suit other organizational goals. The overall experience development framework is shown in Figure 2.

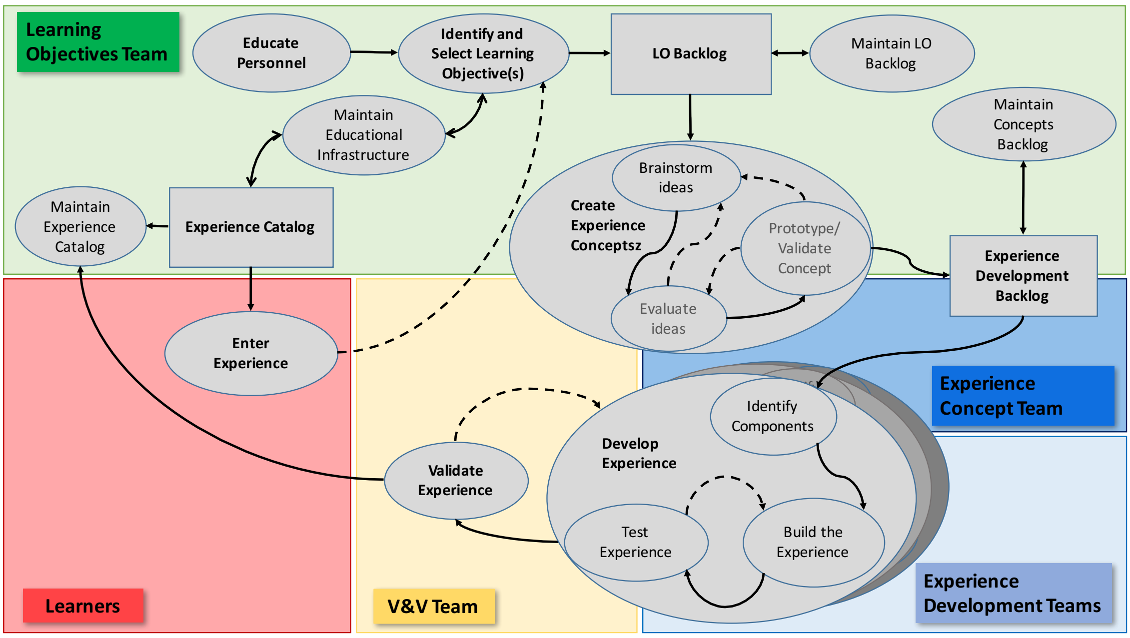

Figure 2. EA Experience Development Framework

Building one or two experiences is hard work, but does not require significant effort. However, after years of interacting with subject matter experts and educational specialists, and the development of the initial prototype experience, the SEEA team is convinced that there are four key areas required to effectively generate experiences, organize and maintain them, and use them to improve an organization. Each area is represented by a team with specific skills. The following paragraphs introduce those teams.

Learning Objectives (LO) Team. This team is made up of organizational learning administrators, managers, and the organization SE experts who would normally mentor less experienced personnel. This team represents knowledge of the needs of the organization, and understand the challenges of its SE environment. It identifies, develops and maintains the learning objectives key to the organization's success. The LO team is also responsible for determining the educational infrastructure and planning to determine how best to use the experiences as they are developed. This can include identifying the priority of experiences to be created or developed, dependencies or paths through the experiences (possibly a form of curriculum), establishing access and policy for learners including the benefits of entering the experiences.

Experience Creation (EC) Team. This team is made up of organizational SE experts (may overlap with the LO Team) as well as experienced personnel representing other systems engineering as well as collaborating organizations or users of SE products and services. This team creates the concept for experiences that provide a vehicle for one or more learning objectives. Each experience concept includes: an organizationally representative setting; a target learner; the general timeline, interactions, and flow of activities included in the experience; and the issues, problems, or analyses that are required for the learner to undertake to obtain the learning objective(s). Concepts are vetted through paper-based prototype execution collaboratively with the LO team.

Experience Development (ED) Team. This team consists of SE experts, prospective learners, and EA tool users. It represents the knowledge of the day to day interactions and activities that add verisimilitude and intensity to the experience concept, and the technical aspects of the EA. This team implements an Experience Accelerator experience that captures the concept and LOs, is executable via the EA (either as single or multi-player implementations), and can measure learning through retrospective (post-experience) activities of the learner and through the appropriate actions and outcomes of the experience.

Experience Verification and Validation (EVV) Team. These are Senior Engineers that are not part of the concept or development teams, and external subject matter experts. This team validates the realism of the environment and activities, the achievement of the LOs, and helps calibrate the learning assessment scoring and difficulty of the experience. This group is involved in ongoing V&V during the development, but their key objective must be to certify to the LO team that an experience is ready for use.

Design Flow Description.

First there is a short period to **educate the personnel** where senior systems engineers (mentors) and others are introduced to the EA concept and how it works. Once oriented, the mentors **identify and select high-priority learning objectives** (LOs) that are important for systems engineers to understand in the new domain. This can be accomplished individually by team members, or in collaborative activities. LOs may be associated with:

- Management or political situations
- Specific technical risks
- Problematic behaviors
- Landmines
- Corporate best practice
- Ethical judgment

The LOs form a backlog from which the organization collaboratively **creates experience concepts**. This initial work gathers groups of related LOs and brainstorms experience ideas about an experience that addresses them, and creates a draft high-level scenario, context and broad outline of a vignette. When a concept seems matures enough to be developed, it is prototyped on paper and "played" by the concept team along with members of the LO team and SMEs. If it is deemed ready, all notes from the players are included in a concept development package and it is added to the development backlog. Otherwise, it returns for additional conceptualization or is eliminated. Experience development packages are then selected for development from the backlog according to NGC-specified criteria (e.g. priority, available staff, impact) and teams assigned to the work.

Develop Experience is a joint activity among a team of domain experts, potential learners, and EA coaches. The work collaboratively and iteratively captures, organizes and enhances knowledge that is often tacitly held. The team analyzes the components of the learning objective(s) and the proposed context to identify the basic material for a vignette in which one or more learners encounter a situation that illustrates the nuances and challenges of the targeted learning objectives. These components might include:

- Persons involved
- Type of project most likely to evince this situation
- Critical factors
- Critical mitigating actions
- how the situation manifests over time
- Data needed to recognize and correctly respond to the situation
- Sources of the data

Building the EA experience is a challenging iterative activity. Among the tasks are specifying:

- What information the learner(s) can access and in what medium
- How information is presented to the learner
- How information is simulated and kept up to date
- The accuracy of presented data: is it true, fuzzy or contradictory and when it might change and under what conditions
- Which non-player characters (NPCs) are automated and which are live
- How NPCs interact with the learner
- Dialog trees and selections for the automated NPCs
- How learner decisions, changes, or questions are communicated
- How learner actions are scored and evaluated
- Range and adjustment mechanisms to tailor the difficulty of the experience
- Retrospective activities for the learner upon completing the experience

The team can use the various tools to iteratively create an engaging and accurate environment and vignette and represent it in terms of a single or multiple player EA experience. All the team members, particularly the possible learners, will gain deeper understanding of the domain from developing and refining the experience.

Each iteration of the experience must be tested by the development team and evaluated by the V&V team, including SMEs. Once complete, it must be certified by the V&V team. This ensures that there are no undetected biases or assumptions, and that the experience is achieving the desired learning outcome(s). Once validated the experience is placed into the organizational **experience catalog** and made available to employees outside of the team.

The LO team decides how employees access the catalog, the order they execute experiences, and how their progress is measured. Individual development plans or more formal curricula are ways the organization can tailor the available material for each learner. Feedback from learners (or other participants) should be used in continuous improvement activities, such as:

- Correcting bugs
- Revising/refining the vignette or the user interface
- Creating a similar vignette but in a different environment or lifecycle phase
- Additional ideas for increasing or decreasing the difficulty.

New learning objectives or requests for modification can be added to the experience backlog. The create experience activity can be repeated while there are learning objectives still in the backlog and team resources are available. As the library of experiences grows, it may be useful to generate variants of experiences to provide different information or situations. The flexibility of the experience development tools provides a relatively easy means to build and improve the Experience Library. The learning objectives team can also refine and strengthen learning objectives and the process for learners.

Case Study: UK MOD In-Service Safety

UK MOD intended to create a training task that is designed to give engineers an idea of the types of problems that they could be asked to analyze and provide guidance on while working on in-service support within Defence Equipment and Support (DE&S). The experience is designed to help engineers understand the practical application of engineering decision making within the in-service support environment. While the purpose of this experience is to present some of the difficulties that could occur when dealing with different stakeholders and stakeholder priorities, it is also important to present to engineers how detailed technical understanding and effective decision making is critical in-service.

The DE&S team already had a classroom experience that was used to give recently joined graduate engineers experience in safety critical engineering decision making. The scenario was based upon three historical accidents, the loss of the Space Shuttle Columbia in 2003 (NASA 2003), the loss of a Nimrod reconnaissance aircraft in Afghanistan in 2006 (Haddon-Cave 2009) and the loss of HMS Thetis in 1939 (Royal Navy 1956). While effective, the training scenario was very manpower intensive, requiring three hours of instruction with a Chief Systems Engineer and Junior Engineer for each cohort of sixteen graduate engineers. It was hoped that the EA would be far cheaper to deliver than the classroom experience.

The experience context is a military maintenance setting. In this scenario, the fictional Royal Navy submarine HMS Tempest has just completed operations and is currently located off the north coast of Australia. The vessel is expected back in Faslane in Scotland for scheduled maintenance in 35 days. There is significant pressure from Navy Command for the submarine to arrive home in time for its maintenance period, to maintain the patrol and operational schedules of the entire submarine fleet.

If the students undertake the diagnosis correctly, they will uncover a serious safety problem that would lead to a loss of the submarine. If they fail to diagnose the problem or realize its significance, then the submarine has a serious accident leading to multiple loss of life.

Design Flow. Following the design flow mentioned in section 3. The experience design team started by identifying and selecting high-priority learning objectives (LOs). The LOs identified are mainly associated with management situations and specific technical risks. They include:

- The learner will be able to understand the difficulties that could occur when dealing with different stakeholders. They need to demonstrate their understanding by using an informed approach to a conversation.
- The learner will be able to prioritize different stakeholder needs under deadline pressure. They need to demonstrate their capabilities by performing tasks in the correct order.
- The learners will be able to use the right communication skills to channel information during in-service scenarios. They need to demonstrate their skills by asking the correct questions and asking the questions correctly.
- The learners will be able to discover a safe and effective solution among mixed information under time-pressure. They need to demonstrate the capability by analyzing mixed information and providing the best solution available.

The team created the experience concepts based on these learning objectives. Because much of the experience is focused on interaction among stakeholders at various levels and in different organizations, the NPCs were developed to represent specific personality types. The MOD based these on the Hudson model (Hudson 2001) as adapted by Parker (Parker, et al 2006).

During the concept creation process, several high-level scenarios were created. These scenarios are mainly meeting and dialog based, provide the student options to choose different styles of communication, and produce different results based on the student's actions. The decisions as to whom to talk to and how to respond to their concerns is managed through a scoring matrix supported by the experience delivery system.

The development evolved iteratively with a new version each week. The team identified the basic experience material components, by analyzing the components of the earlier identified learning objectives and the proposed context.

Experience Flow. The MOD experience flows through five baseline phases designed for this experience. These are shown in Table 3.

During the development, tasks are specified to better define the experience and to provide define the types of implementations of the experience. Including the use of emails, phone calls, the presents of a deadline pressure, the pressure from higher ranked officers and the attitude of the peers. For example, the following experience components were specified during the development:

- Learner can access the background information about the experience in the forms of emails and pdf files.

- Learner is presented with a time-sensitive issue which are both challenging and complex.

- Learner can receive intel about different aspects of the problems by talking to NPC characters. These players are automated and interact with the learner in different kind of mood, depending on the relationships between the two and the way learner(s) ask questions. There are limits on the time available and the number of NPCs the learner can talk to.

- Supervisor NPC asks the learner to explain the issue after the investigation

For Phase 0, a welcome window shows the learner the background information about the experience; specifically, about their recent appointment and responsibilities. The learner then receives a phone call from the supervisor Tim Parker (Combat Systems Chief Engineer) stating that the learner needs to familiarize with the basic configuration and operations, as well as the overall information about the tasks. He then sends out an email to the learner asking for a plan, and requesting the learner to work through the different materials available in the folders. The learner proceeds to the next phase after reading through all the PDF files in the folders.

Table 3. Phase Design for the MOD In-Service Experience

Phase	**Phase Description**		
	Phase Activity Focus	Ending Event	Activities
0	Pre-work	Learner feels ready to “go to work”	Learner is advised of the team status (only the learner is on duty) and to study information relative to the team’s purpose
1	Interruption	Tasked to investigate and make recommendation	Message from Tempest re: damage to torpedo tube
2	Investigation	Completes investigation	Contacts other personnel about the safety issues involved
3	Decision and Recommended Action	Experience ends	Considers all information; makes recommendation
4	Reflection	News report based on the performance	Receive information about their decisions and reflect on learning objectives

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At the beginning of the Phase 1, Mark Snell (Delivery Team Lead) calls in and asks the learner to read urgent emails and reply with immediate decision. The decisions here involve whether to forward the critical information about the ongoing situation to a supervisor who is on vacation or not. Many different options are designed to test the learner’s responsiveness and communication skills. If the learner chooses not to investigate the issue, which in this case meaning defying the recommendation of officer with a higher rank, the experience will move to Phase 4 directly with a failure scenario. If the learner decides to investigate the situation, they can choose to inform the supervisor which would potentially ease the investigation.

During Phase 2, learner has an opportunity to talk to different team leaders (NPCs) to gather vital information about the potential cause and the severity of the problem. Both helpful and misleading information is presented to the learner. To fully solve the problem, the learner must talk to the right persons and ask the right questions. The learner proceeds to the next phase by either learning the information needed, or running out of time or the number of NPCs contacts allowed.

For Phase 3, Tim Parker calls the learner and asks for a report regarding the ongoing situation. The learner then needs to provide information about their investigation. The dialog options are limited to cover only what the learner has received in the investigation. At the end of the report, the learner ultimately decides if the submarine should sail.

Reaching Phase 4, learner will receive a new performance briefing. If the learner successfully investigated the problem and discovered enough information to convince the supervisor not to sail the submarine, the news briefing will report so. However, if the learner failed to achieve the goal, the news briefing reports a submarine loss as a failure scenario.

Results. Overall the development of the HMS Tempest experience went well. The underlying EA framework supported the existing MOD scenario well.

The basic structure of an EA toolset fitted in well to the MOD scenario. Both followed a similar mix of high level linear chapter to chapter flow, with a non-linear exploration within chapters. In both cases students discover information through interaction with NPCs and documents/reports.

The MOD scenario explored a different aspect of the experience accelerator than the original UAV scenario. The scenario timescales were not as compressed as the UAV scenario, events happening over a three- to five-hour period. The simulation was, however, a 'once in a career' event – where the student could stop a major accident from happening. This offers the potential to contribute to the MODs maritime safety strategy, as it lets everyone experience very low likelihood but high impact events.

Converting from a classroom-based exercise to an SEEA-based one had some challenges. It was necessary to think through the issues in much more detail than when using an expert delivery team. While many of the artefacts (system schematics, product specifications, failure mode analysis) produced for the original scenario could be used with no changes, it remains that the conversion required similar effort to developing the original training strategy.

The EA toolset was surprisingly easy to use. The scenario made significant use of the ChatMapper® toolset. There was little need for programming experience. However, the authors found that storytelling, game design or instructional design experience would have been useful. This was a challenge to the MOD, who could provide detailed domain and general engineering expertise, but did not have game design expertise.

Finally, the work required good working relationships. The team was working in two different countries with a five- to seven-hour time difference. Two factors helped successful delivery. First, The Technical Cooperation Programme provided an overarching legal framework to work within (http://www.acq.osd.mil/ttcp/). Second, the team could build upon existing relationships between key players developed during previous INCOSE work.

Summary and Future Work

The SEEA was used successfully by an organization outside of the SEEA development team to create and deliver an experience. Unlike the prototype experience, which was built around a complex system dynamics model, the Tempest experience was primarily built around personal interaction. It also had a much shorter time frame and more limited scope. The SEEA team is continuing to test the tool set internally, and will continue to conduct tutorials and workshops in experience development to validate and improve the tools.

The Delivery System is being revamped and upgraded to an HTML5 infrastructure to provide better capability and meet the web accessibility requirements of the US government for its use by government personnel. The Development System while not required to meet all the accessibility requirements, is also evolving; new features are being added and new tools developed. Interest in using the SEEA technology has extended beyond the defense systems engineering community to include education, healthcare, and other industrial environments as well.

The SEEA is currently being used in three academic environments. The US Defense Acquisition University, the University of Alabama Huntsville and the Air Force Institute of Technology are planning to collect additional metrics from their systems engineering classes in the spring, summer and fall of 2017. An updated learning assessment tool will be used to support and analyze the information from these classes, and will help determine if SEEA's immersive experience provides a measurable advantage over the traditional lectures.

As an open source, openly available tool, the team is actively building a community of users and developers around the Experience Accelerator. As the community evolves, more types of simulations will become available and additional interaction techniques developed. For example, another SERC task, one developing simulations of agile, lean and similar adaptive governance mechanisms in systems development, is actively working to provide its capabilities within the SEEA environment.

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Biographies

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