Systems engineering a 21st century introductory course on systems engineering: the Seraswati Project[1]

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Abstract. Systems engineering has traditionally been a difficult subject to teach. This paper documents the development of the world's first postgraduate immersion course in systems engineering referencing earlier publications upon which the project was based and concludes with some lessons learned. The course pedagogy reversed the traditional lecture-to-activity ratio of about 9:1 using problem-based learning activities and focussed on applying systems thinking, how to do systems engineering as well as what to do in the various phases of the systems development lifecycle. During delivery of the course in a four-day block format, student teams worked on two projects at the same time, thus learning about systems engineering and acquiring time management, problem solving, analysis, team working and other skills pertinent to their work. The results were that while the students initially went into shock when faced with the workload, their understanding of the concepts seemed to be better on the second day of this four-day course than the understanding demonstrated by students at the end of earlier lecture-centric five-day courses.

Introduction

This paper documents the reasons for developing the course (system), the curriculum content and design and integration of the courseware modules (subsystems), the pedagogical challenges faced, and the results in the classroom in Singapore and the UK. The development process was basically a conversion from a lecture-centric format to an activity based learning format and is applicable to any engineering subject.

The reason for developing the course

The world is turning to systems engineering to help acquire and maintain the complex systems that underpin our 21st century civilization. As a consequence, demand for skilled, knowledgeable, systems engineers in government, industry, and academia is increasing around the world (Arnold 2006). However, in general, systems engineering seems to be poorly practised (Kasser 2007). One reason for this situation is a hypothesis that systems engineering is poorly taught[2], and one reason for the poor teaching is the combination of the lack of good teaching materials and delivery methods that bear little relationship to the environment in which modern engineers collaborate and make decisions. On the other hand, if a good course could be developed and delivered, the practice of systems engineering

[1] The development of the course was made possible by a grant from The Leverhulme Trust to Cranfield University.

[2] In making this observation to practicing systems engineers and academics in the US, UK, Australia and Taiwan over several years, only one person disagreed with it.

should be improved. The Serawati[3] project was set up to develop such a course, deliver it, and then develop associated materials to allow the course to be taught by different instructors in various institutions.

The project has progressed to the point of having developed and delivered the course, producing the world's first postgraduate immersion course in systems engineering. During the delivery of the course in a four-day block format at Cranfield University (November 2007) and the National University of Singapore (NUS) (January and May 2008), the students in the courses demonstrated a better understanding of systems engineering on the second day of the four-day course, than students at the University of South Australia (UniSA) had shown at the end of traditional five-day courses.

The research questions

This research used a systems engineering approach to first identify the gap between what was being taught and how it was being taught, and what was needed and then develop a better introductory course on systems engineering that met the needs of the stakeholders. The methodology for developing this course is based on the systems engineering process, namely defining the problem, considering alternative solutions, evaluating the solutions and finally constructing and testing the design.

The systems engineering problem was, "to design and construct a course that would produce more effective systems engineers". Solving the problem would require answers to the following four research questions –

- Who are the stakeholders?
- What should be taught? (the content)
- How should the course be taught? (the method)
- What would it take to create a 21st century course that taught the right material and would be delivered using effective learning techniques? (the curriculum)

Each question was considered in turn, and the responses produced the basis of the requirements for the system, which is defined as the course.

Question 1: who are the stakeholders?

The stakeholders were identified as being identical to the stakeholders for degrees previously crafted at UniSA and University of Maryland University College (UMUC), namely employers (government and industry), students, instructors, the university, and the entity that pays the cost of tuition (either the student or the employer) (Kasser et al. 2004).

Employers. Employers would invariably be interested in their staff acquiring valuable knowledge and skills that would translate into enhanced workplace performance in the short term as well as in the long term. Some employers also prefer flexible delivery methods to allow employees to have access to their classes at convenient times, or attend classes while on travel. Others, particularly the Defence forces, are desirous of enabling personnel on lengthy out-of-town assignments to be able to attend classes. Employers' needs contain the following items.

[3] Saraswati is the Hindu goddess of knowledge possessing the powers of speech, wisdom and learning. The project was named by changing the Sa to Se for systems engineering.

- Competent[4], skilled and knowledgeable systems engineers capable of effectively working on various types of complex integrated multi-disciplinary systems in different application domains, in different portions of the system lifecycle, in teams, alone, and with cognizant personnel in application and tool domains.
- Coursework that does not interfere with employment. This means flexible delivery modes to allow students to take the course as and when they can from whatever location they happen to be in.
- Knowledge, skills and competencies, which are useful immediately, and in the short and long terms.
- Ability to communicate systems engineering principles to others.
- In the acquisition portion of the system lifecycle, facilitate the effective acquisition of systems that meet the customer's needs at the time the system is specified, is actually acquired and during the full length of its operational life.
- Engineers who are effective at solving open-ended problems (Durward K. Sobek II and Jain 2004).

It was recognised that "effective systems engineering calls for careful coordination of process, people and tools. Such coordination cannot be learned from books" (Hall 1962) page v).

Students. Students in these courses are typically mature-age, working at their day jobs, concerned with family issues, and studying part time. They often cannot take classes in the traditional undergraduate manner of full-time study, or regular attendance on campus in the face-to-face classroom. Students' needs include:

- Enhanced career opportunities[5].
- A study workload that is appropriate to the lifestyle of a full-time employee with a family.
- An understanding of what systems engineering is all about and why every system engineer describes it differently.
- An understanding of how what has been learnt in the class maps into their employer's processes.
- A course experienced in a manner that makes learning effective.
- Affordable text books[6].
- A clear understanding of how their work in the course will be assessed[7].

Instructors. The ideal instructor for these courses is an accomplished practitioner working

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[4] Systems thinking has been identified as a key skill.

[5] Some students attend these classes with more knowledge than the instructor. These are the ones who have the experience, but not the paper qualifications. Other students have no experience and little knowledge of the subject.

[6] Experience with post graduate students at The George Washington University (GWU), UMUC and UniSA indicates that students prefer courses with text books that can be put on their bookshelves for future reference over photocopied notes, even if the notes are bound into books. Moreover, since some students had to pay for the books even though they get their tuition refunded, they got annoyed when listed text books were not fully used and complained to the program director. Student then learned not to order the text books until after the first classroom session and hearing the instructor discuss the use of the text books in the context of the class. Consequently, they didn't get the books until the second or third session.

[7] This has been found to be important in courses delivered to students in the Master of Project Management degree offered to the Australian Defence Materiel Organisation (DMO) by UniSA. The students perceived that the grades had an influence on their future in the organization.

in the field (day job) and teaching part-time and generally does not have the time to prepare course materials. Instructors' needs include:

- Lecture materials – presentation graphics and notes.
- Lesson plans.
- Exercise materials.

Universities. Universities' needs include:

- A marketable course.
- A high-quality product.
- A teachable course in the traditional semester mode, as well as online using both full-time and part time instructors.
- Components that can easily be incorporated in existing engineering and information technology courses.

Question 2: what should be taught?

The modern text books in systems engineering tend to be designed for practicing systems engineers focussing on the details, lack a big picture (of systems engineering) perspective, and while the better books make excellent desk references, the books are not optimal for teaching at the introductory level. Moreover, current books and other publications tend to present systems engineering from a single perspective (Thissen 1997) – that of the author. In addition, each author has a different perspective! Prior and parallel research into the nature of systems engineering (Kasser and Palmer 2005; Kasser 2007, 2007) showed that much of the confusion about the nature of systems engineering and the roles and activities performed by systems engineers are the result of viewing the situation from a single perspective (a lack of systems thinking). This situation is reflected in the current generation of courseware, which perpetuates the situation, resulting in a closed loop.

To be a better course, the content of the course should provide the students with the answers to the following questions.

- What is systems engineering?
- What do systems engineers do in the workplace?
- What is a systems engineer?

An examination of the reviews of systems engineering education such as (Brown and Scherer 2000) and published syllabi of current postgraduate programs on systems engineering discovered a wide variety of courses with no consensus on answers to these three questions. To meet the need for a better course, an understanding for this lack of consensus was required. However, much of the research into the three subject matter questions had already taken place - see (Kasser 1996; Kasser 1997; Kasser and Massie 2001; Kasser 2002; Kasser and Palmer 2005; Kasser 2007; Kasser 2007). Consider each question.

What is systems engineering?

After more than 50 years of systems engineering, systems engineers still do not have a single definition of systems engineering that is accepted by all (or even most) systems engineers. Findings from research into this situation which examined the origin of systems engineering and issues with adjacent and overlapping disciplines (e.g. project management), produced the Hitchins-Kasser-Massie (HKM) context of systems engineering Framework (Kasser 2007, 2007) which is incorporated into the course because it provides an understanding of:

- Why systems engineers can't agree on their roles and activities.
- The reasons for the overlap between systems engineering and project management.
- How systems engineering meets the requirements for a disciple as defined by (Kline 1995), and documented in (Kasser 2007).

What do systems engineers do?

This question can be rephrased as 'what is the role of the systems engineer in the workplace?' The literature abounds with discussions on the role of the systems engineer e.g. (Brekka, Picardal, and Vlay 1994; Roe 1995; Sheard 1996; Kasser 1996; Mooz and Forsberg 1997; Kasser 2002; Eisner 2002; Kasser and Palmer 2005; Kasser 2005; Faulconbridge and Ryan 2003; Maier and Rechtin 2000; Wymore 1993) and (Alleman 2005). (Kasser 2005; Kasser and Palmer 2005) separated the role (job) of a systems engineer from the activities in the workplace that are generally known as systems engineering. The findings from this research were incorporated into the course to explain why (1) different systems engineers have different perspectives on the role of a systems engineer and (2) the relationship between systems engineering and project management, and leads to the next question.

What is a systems engineer?

Again there is little consensus on the answer to the question. The simple answer is systems engineers are people who do systems engineering. However, (Kasser and Palmer 2005) showed that was not true. Consider (Hall 1962) pages 16-18) who provided the following specifications or traits for an "Ideal Systems Engineer" grouped in the following areas:

- An ability to see the big picture.
- Objectivity.
- Creativity.
- Human Relations.
- A Broker of Information.
- Education - Graduate training in the relevant field of interest (application), as well as courses in probability and statistics, philosophy, economics, psychology, and language.
- Experience in research, development, systems engineering and operations.

Hall concluded by stating that "the ideal" was not available because the scope of the task is beyond the capabilities of a single individual, thus mixed teams of specialists and generalists were employed. (Hitchins 1998) states "[systems engineering] is a philosophy and a way of life". Later studies include (Frank 2002) and (Frank 2006) who consolidated and classified the characteristics of successful systems engineers into ten cognitive characteristics, eleven abilities, ten behavioural competences and fifteen dealing with knowledge.

The characteristics of a systems engineer can be summarised based on the increasing ability of the person to deal with vagueness as:

1. None: Those who can do systems engineering when told how to implement a solution;
2. Some: Those who know what to do to implement a solution and can figure out how to do it;
3. Lots: Those who can define the problem in the manner of (Wymore 1993) page 2) and then determine what to do to implement a solution and how to do it.

Systems thinking

The need for systems thinking was widely recognized, and figuring out how to meet the need to apply systems thinking in a systemic and systematic manner constitutes a problem yet to be solved (Kasser and Mackley 2008). The literature was abounds with:

- publications advocating the use of systems thinking, e.g. (Flood and Jackson 1991),
- one or two publications describing how an understanding of the way things are connected together provides one with a competitive advantage over those who do not share the same understanding (Morgan 1997; Luzatto circa 1735),
- philosophical and academic theories of systems thinking, e.g. (Flood and Jackson 1991), and
- the need to view problems from various perspectives, e.g. (Morgan 1997).

The only systematic approach to applying systems thinking discovered in the literature was the seven streams of system thinking (Richmond 1993). The research behind the curriculum development produced a similar set of nine streams or viewpoints called System Thinking Perspectives (STP) (Kasser and Mackley 2008). The STPs were applied in the course in an activity called active brainstorming. Traditional brainstorming is passive in the sense that it waits for ideas to pop up. Active brainstorming uses the STPs to trigger ideas, hence the name active brainstorming.

The next challenge was how to assess the students for their ability to apply systems thinking. While there were various definitions of systems thinking and critical thinking, the problem of measuring the degree of systems thinking seemed to have already been solved (Eichhorn 2002; Wolcott and Gray 2003). (Eichhorn 2002) informed students that their written answers would be judged for their clarity, accuracy, precision, relevance, coherence, logic, depth, consistency, and fairness. (Wolcott and Gray 2003) aggregated the skills for critical thinking by defining five levels of critical thinking. In addition, Wolcott's method for assessing a critical thinking level was very similar to that used by (Biggs 1999) for assessing deep learning. Since a modified version of the Biggs criteria had been used successfully at UniSA (Kasser et al. 2005), Wolcott's method was adopted for the course.

At this point the knowledge and skill components of the course had been defined, so ways of maximising the effectiveness of the classroom experience were researched.

Question 3: how should the course be taught?

Experience at the Systems Engineering and Evaluation Centre (SEEC) at UniSA in traditional lecture format classes has shown that students sat through the lectures, complained of "death by PowerPoint", and appeared to understand the content. However students who failed to complete the post-class assignment were still able to pass the course (albeit with a minimum passing grade) (Kasser et al. 2005). The students were learning to do systems engineering by numbers![8] A change was needed.

The literature review on systems engineering education and curriculum design (e.g. (Asbjornsen and Hamann 2000; van Peppen and van der Ploeg 2000; Sage 2000; Brown and Scherer 2000; Thissen 1997; Jain and Verma 2007)) found that publications tended to focus on the body of knowledge for systems engineering and tended to ignore pedagogical issues and systems thinking. Thus the pedagogy would need to be researched to identify factors that made learning effective and ways of shaping the classroom experience to incorporate those factors would need to be explored, designed and tested. There is a wide body of literature that

[8] The idiom refers to a popular amateur method of painting a picture using a pre-printed canvas with areas outlined in numbers in the mid 20th century. When the area had been painted in a colour corresponding to the number, the picture was reasonable and complete.

provides pertinent information for changing the pedagogy some of which is summarised in this section.

Concepts within cognitive psychology have major implications on the process of education. For example, (Bruning et al. 2004) present seven themes from cognitive psychology that are relevant to teaching and learning. These are:

- Learning is a constructive not a receptive process.
- Mental frameworks organize memory and guide thought.
- Extended practice is needed to develop cognitive skills.
- Development of self-awareness and self-regulation is critical to cognitive growth.
- Motivation and beliefs are integral to cognition.
- Social interaction is fundamental to cognitive development.
- Knowledge, strategies, and expertise are contextual.

(Brown and Scherer 2000) suggested incorporating the following features into the classroom experience:

- use of open-ended problems;
- encouragement/development of student creativity;
- use of the systems design methodology;
- consideration of alternative solutions;
- detailed system design specifications;
- use of decision methodologies;
- consideration of feasibility, reliability, and maintainability;
- inclusion of economic, social, ethical, aesthetic, and economic impacts;
- use of real problems with real clients.

(Sage 2000) cited (ASEA 1994) which suggested that the ingredients associated with reshaping the curriculum were:

- team skills, and collaborative, active learning;
- communication skills;
- a systems perspective;
- an understanding and appreciation of diversity;
- appreciation of different cultures and business practices, and understanding that engineering practice is now global;
- integration of knowledge throughout the curriculum a multidisciplinary perspective;
- commitment to quality, timeliness, continuous improvement;
- undergraduate research and engineering work experience;
- understanding of social, economic, and environmental impact of engineering decisions;
- ethics.

Research into the cognitive approach to the learning process suggested that one of the most important elements was what the individual brought to the learning situation (Woolfolk 1998), namely, prior knowledge. Exercises could be designed to leverage this prior knowledge.

The pedagogy also needed to take into account that the retention information by students varies according to the delivery method. According to the often quoted learning pyramid developed in the 1960’s at the National Training Laboratories, Bethel, Maine (Lowery 2002), and the earlier Dale Cone of experience (Dale 1954), listening to lectures and reading are the worst ways of learning yet that seems to be the way current courses are being delivered

There also seems to be a correlation between (Dale 1954)'s experiential factors that promote retention and (Biggs 1999)'s deep learning. The pedagogy of the classroom needs to be changed to maximise, or at least increase the retention rate of the knowledge, and allow the students to practice and develop the needed skills. In addition to lessons learned from the literature review, the actual experience of changes in the pedagogy from a teacher-centric to a student activity problem solving format while teaching systems and software engineering in the classroom and via distance learning at UMUC (Kasser and Kirby 1999), was considered when developing the pedagogy for this course.

Moreover, in a postgraduate course, the emphasis must be on conditional knowledge, since the application of conditional knowledge would demonstrate mastery of the subject. Yet, benchmarking systems engineering courses from other institutions found that much of systems engineering is taught as declarative and procedural knowledge (by describing the process of systems engineering).

Question 4: What would it take to create a 21st century course that taught the right material and would be delivered using effective learning techniques?

The process for creating this single course (the system) was based on that used to craft postgraduate degrees at UMUC and to craft bespoke postgraduate degrees at UniSA for the Australian Defence Science and Technology Organisation (DSTO), and Defence Materiel Organisation (DMO) (Kasser et al. 2004; Kasser et al. 2005). When the scope of the work to develop the curriculum (subject matter and delivery methodology) was estimated[9] it became clear that the project would take at least six months of full time research and development.

The course

The name of the course is, "Integrated Multidisciplinary Engineering for the 21st Century". Unlike current similar courses which focus on the systems engineering process for the knowledge component process, this course:

- Views systems engineering from the problem solving perspective.
- Focuses on the three legs of a systems engineer (Kasser 2007) which are:
  1. systems engineering,
  2. the application of systems thinking, and
  3. interpersonal communications.

The structure of the course showing the linkage between these elements is shown in Figure 1[10]. The course provides a flavour of systems engineering with a broad overview discussing the context for systems engineering, the competencies needed to perform systems engineering and the phase of the lifecycles employed in systems engineering. The application and assessment of systems thinking in the various phases of the project lifecycle is employed in the problem based learning exercises to enhance the learning experience. The repetition in the exercises improves competence in the appropriate skills needed by the systems engineer.

[9] Underestimated as it turned out.

[10] The terms ORP, HKMF, SPARKS, FRAT, active brainstorming and systems thinking perspectives are explained in this document.

Desired outcomes

At the end of this course, participants should:

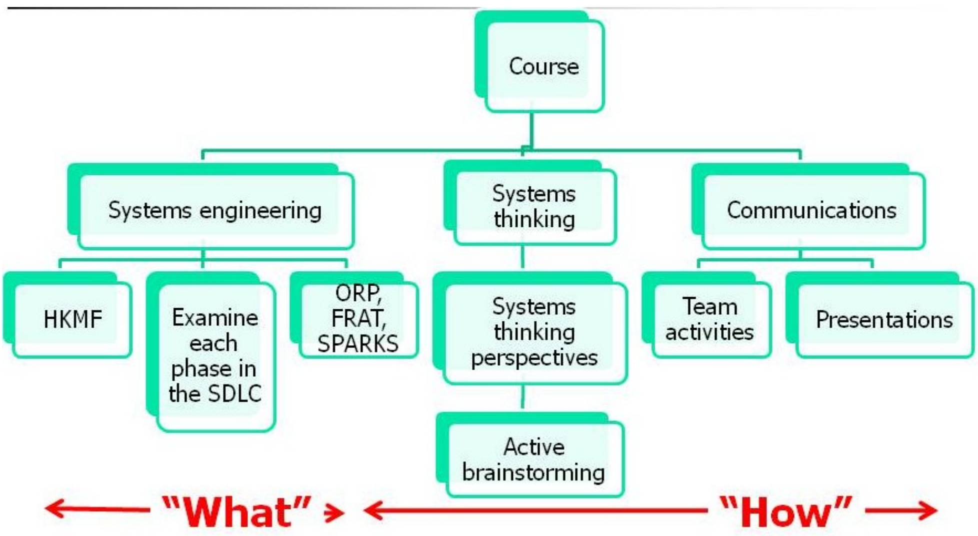

Figure 1 Structure of the course

- Have improved systems thinking and critical thinking abilities.
- Understand the reasons for the different definitions of the term "system", and the various viewpoints on systems engineering.
- Be able to identify the various types of problems faced by systems engineers in different phases of the system lifecycle.
- Be able to identify an appropriate tool or methodology to solve the problem.
- Understand the need for systems engineers with different competencies, skills and knowledge in different parts of the system life cycle.
- Understand that there isn't always a single "right" solution to a problem.
- Be better than average systems engineers for their level of experience.

The pedagogy of the course

The curriculum design was a mix of the objectivist and constructivist approaches to instructional design (Nuldén 1997; Vargo 1997; Jonassen et al. 1995). It combined the traditional lecture (*teacher centere*d) with the highly interactive and collaborative practical exercises (*student centered*). As such, the focus of the course is on 'practice by doing' in the form of team exercises, and 'teaching others' in the presentations made by the students at the end of each module. With problem-based learning scenarios, the team members could contribute their prior knowledge (or knowledge from any pertinent external sources), and construct learning from practical activity.

Courseware modules

The modules were designed so that there would be learning from different sources of knowledge. Each module would start with a short lecture to set the context. During the team exercise, the students would divide the readings into parts, with each student reading a part. The primary purpose was acquiring the knowledge in the readings, while the secondary purpose was for the students to each become "experts" in what they read, and then bring that expertise to the team. This emulated the real world of multidisciplinary teams, where they would have to deal with subject matter experts and develop a trust of their level of competency. The design goals for the module components were based on

- meeting the knowledge and skills requirements identified from the stakeholder needs,
- being in accordance with modern pedagogy which stated that listening and reading were the worst ways to retain information, while doing and teaching were the best, and
- the need for systems engineers to be able to work together in teams.

The following components were designed accordingly to ensure the students needed to use and hence develop systems thinking skills:

- A set of PowerPoint slides for a lecture.
- Supplementary presentations containing self-evident PowerPoint slides.
- The accompanying instructor’s notes for what knowledge to highlight during the lecture.
- Exercises – accompanied by suggestions of what to do, what to expect the students to produce and how to assess the results.
- Summaries of the readings to use when discussing the exercises with the students during the classroom exercises.
- Chapters in a text book that supplement the lecture. However, since there is no single textbook that fits this class, a set of readings, listed in each module was provided to the students to supplement the text book.

The team exercises were set within a single context, minimizing the time students need to become familiar with the context before actually performing the exercise in the manner of (Kasser and Williams 1999). Each team would work on the same project independent of the others, to allow comparisons of approaches, demonstrating that there need not be one “right” solution. Each team exercise would terminate with a presentation, and the similarities and differences of the teams’ presentations discussed after all the presentations have been completed. Learning in a team also came from the different perspectives based on the prior knowledge of the team members, while learning as a student cohort also came from the presentations made by the other teams.

Module topics

The modules in the course were designed to cover the following topics:

0. An introduction to the design and construction of the course
1. What are multidisciplinary engineering, interdisciplinary engineering and systems engineering
2. Why projects fail
3. An introduction to lifecycles
4. A framework for understanding systems engineering
5. The competencies of a systems engineer
6. Systems engineering in the needs definition phases of the system lifecycle
7. Systems engineering in the requirements phases of the system lifecycle
8. Systems engineering in the design phases of the system lifecycle
9. Systems engineering in the integration phases of the system lifecycle
10. Systems engineering in the test and evaluation phases of the system lifecycle

11. Systems engineering in the in-service[11] or operations and maintenance phases of the system lifecycle
12. Modelling, simulation and other methodologies, tools and techniques used for systems engineering
13. Wrap up and Student presentations

The relationship between the modules is shown in Figure 2. This is a very different arrangement from most traditional courses which tend to ignore the topics covered in Modules 1, 2, 4, and 5.

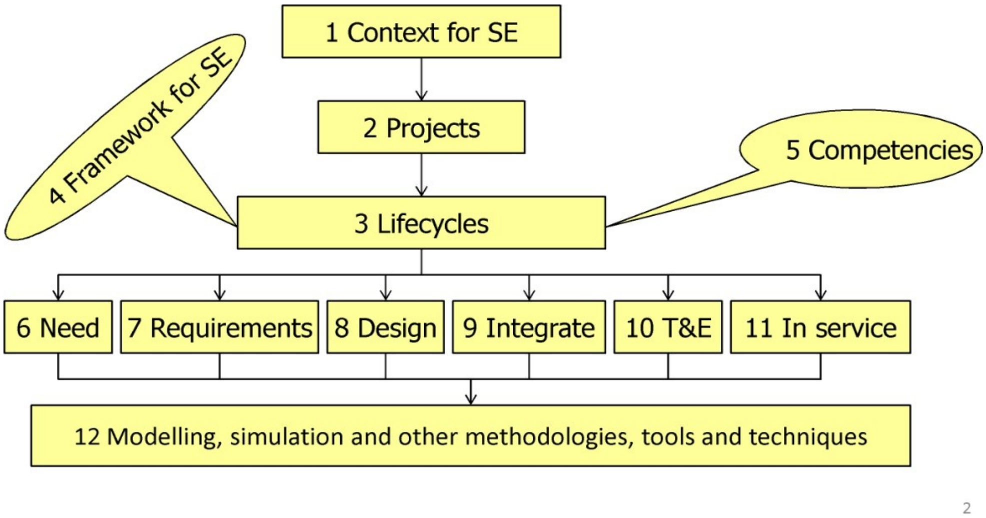

Figure 2 Relationship between course modules

The course was divided into four parts: Part 1 begins with Module 0 which provides an introduction to the design and construction of the course. Module 1 then provides the contextual background to multidisciplinary engineering, systems engineers and systems engineering. Since systems engineering is generally performed in projects, Module 2 discusses the reasons why projects fail and the lessons to be learned from those failures. Projects also take place in the context of a lifecycle, or a series of activities. Thus Module 3 introduces the topic of lifecycles to the students. Since systems engineering is generally performed by systems engineers, Module 4 discusses the knowledge, skills and competencies for systems engineers. Projects take place in the workplace, a system containing many different jobs and disciplines. Thus Module 5 sets the context by showing where and how systems engineering fits into the work of creating and maintaining systems.

Since most systems engineers work in the systems development life cycle (SDLC), Part 2 provides the knowledge about what systems engineers do in the various phases of the systems life cycle and goes into details of the problems faced in traditional systems engineering in the various phases of the SDLC. Consequently,

- Module 6 covers systems engineering in the needs definition phases of the system lifecycle.
- Module 7 covers systems engineering in the requirements phases of the system lifecycle.
- Module 8 covers systems engineering in the design phases of the system lifecycle.

[11] The phase is generally known as in-service in the UK and operations and maintenance in the USA.

- Module 9 covers systems engineering in the integration phases of the system lifecycle.
- Module 10 covers systems engineering in the test and evaluation phases of the system lifecycle.
- Module 11 covers systems engineering in the operations and maintenance phases of the system lifecycle

Part 3 of the course summarizes the nature of problems, methodologies and tools used to solve those problems by systems engineers in the project lifecycle in Module 12.

Part 4 of the course wraps up the course with a summary and a set of student presentations of the products of their practical work in Module 13.

The practical exercises

The purposes of the exercises were:

- to practice systems engineering, and problem solving,
- to understand the scope of multidisciplinary and interdisciplinary engineering,
- to enable the students to grow intellectually and deal with ambiguity and complexity.
- to learn about systems engineering by doing systems engineering, and
- to understand the need for the various competencies, skills and knowledge and develop them. These skills and knowledge needed by systems engineers over the system life cycle can be divided into:
    1. Those needed in several if not all phases of the system life cycle.
    2. Those needed in specific phases of the system life cycle.
    3. Knowledge in the domain in which the system being developed or maintained or upgraded exists or will exist.

The exercises were designed to allow the students to identify their progress and know that they were learning. "Management by objectives" was used as a guide because it allowed for specific objectives to be set for each exercise, and the presentations following the exercise would demonstrate how well the goals were met (or not). The goals for each exercise were set as recommended by (Jain and Triandis 1990) "in such a way that they are (1) specific, (2) difficult, but (3) attainable", given that such a combination of goal attributes resulted in maximum motivation of researchers[12].

The teamwork exercise components of the course were split into the following two team exercises in each module[13]:

- Project Sukumu exercise.
- Staffing exercise.

Within each module, the students could choose to do the exercises serially or simultaneously, and were expected to manage their time with the assistance (and prodding) of the instructor.

Exercise context

The exercises were set in the fictitious Federated Aerospace, a major conglomeration with

[12] The students are doing research in systems engineering in the manner of (Hall 1962).

[13] Yes the time is limited, but that is the real world. The short schedule will encourage the students to think about what is important and what isn't and develop time management skills. The post exercise discussions will be facilitated along this theme to draw out the reasons for their choices.

systems engineering expertise in several commercial and Defence domains. Federated Aerospace has just been awarded a major multi-billion pound contract to develop an integrated transportation system for the country of Engaporia. This contract is known as Project Sukumu. In order to meet the schedule of project Sukumu, Federated Aerospace must raid its current projects for the core personnel. Consequently each current project is going to lose people, much to the chagrin of the team leaders and the personnel left behind. In addition, Federated Aerospace will have to hire replacements for the personnel being taken off the current projects. Each of Federated Aerospace's current projects is in a different application domain and in a different stage of the project lifecycle as shown in Table 1[14].

Table 1 Federated Aerospace's current projects

Project	Phase in the SDLC	Application Domain
Project Nemesis	Needs	Ship acquisition
Project Radiator	Requirements	Aerospace
Project Darwin	Design	Database (online transaction system)
Project Terminal	T&E	Information Technology
Project Octopus	In service	Transportation

Link between module knowledge component and exercises

In general, the lecture and readings cover the activities performed by systems engineers; Project Sukumu provides the learning about the specific problems associated with their implementation of a project over its SDLC while the staffing exercise provides the learning about the skills and competencies needed to do the backfill for their current project in its current phase in its application domain. Since each team presents on a different project in a different domain in a different phase of the SDLC, the students learn about problems, skills and competencies for different projects in different domains in different phases of the lifecycle.

Project Sukumu exercise

This is a traditional class project. The students go through the SDLC process designing an integrated transportation system for a fictitious country.

Purpose. The purpose of the exercise is for each team to:

- develop examples of systems engineering process-products (documents) in the form of PowerPoint presentations from a problem solving perspective,
- develop an understanding of the links between them and,
- begin to understand the consequences of poor documentation in earlier phases of the systems lifecycle.

Activities. During the exercise in each module, the students are expected to:

[14] The first letter of the project name reflects the phase of the life cycle (memory aid).

- Define the pertinent problem or issue
- Identify alternative solutions
- Identify evaluation criteria for making decisions
- Identify the approach to solve the problem/make the decision
- Plan the phase of the project

The point of each specific exercise is to learn:

- what systems engineers do
- what skills and knowledge they need to do it

The point of the Sukumu exercise is NOT to do systems engineering in the traditional sense, namely, the students will not do the task; instead they will figure out what needs to be done, and how it will be done, then produce the work plan for the task to be done. However, the students will develop an understanding that there is the need for some ‘doing’ during the ‘planning’ to determine feasibility (in the process domain). This is the same concept as bread boarding during the design of a system (in the product domain).

The students are requested to reflect on this process and present the results of the reflection as part of their presentations in Module 13.

Staffing Exercise

Purpose. To allow the students to develop an understanding of the competencies, knowledge and skills needed in different types of projects in different phases of the system life cycle and perform some of the activities generally performed in the SDLC. By having the students develop a non-technical system the students will be exposed to the concept that systems engineering applies to all sorts of systems.

Overview. The system to be realized is a project systems engineering team (SET). A SET consists of people with complementary skills. The skills needed on a SET may be different for each phase of the system being developed by the SET (e.g. design skills, testing skills, etc). Each project SET is going to lose people to the Sukumu Project, consequently replacements need to be found. The exercise is to apply systems engineering to the problem of finding replacements.

Details. The students will have to understand competencies, skills and knowledge needed in each phase in the SDLC in order to staff a project. The students are shown how to use a systems engineering approach to developing the requirements (what is being done to determine and solve problems (use cases), identify the competencies needed to develop a job description (requirements for personnel), perform a gap analysis between the existing project team skills and select from a set of resumes to fill the gap in an optimal manner (design and integration). The comments on the presentation of their work by the instructor and other students provide the test and evaluation function.

The post-presentation discussion

After the students had presented there was to be a brief discussion about the presentation highlighting the use of presentation techniques. The students would be encouraged to copy good techniques used by other teams[15].

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[15] This is the only instance in which plagiarism is permitted, nay encouraged☺.

Development of the course

The hardest part of the development was the need to reduce the lecturing component, but still impart the knowledge. This was done by a combination of:

- The courseware components.
- Not only allowing time for the students to read the material during the exercise, but making it an essential emulation of the systems engineering workplace.
- Ensuring that the instructor walked around between the teams, monitoring what they were doing, answering the rarely posed question, providing guidance for how to proceed, and making sure the teams met the schedule (completed the exercise within the module).
- Designing the exercises, so that the first exercise was also a teambuilding exercise, the second exercise also set a baseline for student self-evaluation, and the remaining exercises built on each other.

Systems engineering environment emulation

As an immersion course, the course emulated the systems engineering environment in several ways including

- Students learned that projects fail for a number of reasons including poor communications between supplier and customer and poor requirements management.
- Unlike in the typical classroom a complete set of instructions and information could not be found in a single place.

These points were emphasised in the pedagogy as follows:

- The students were informed that information needed to complete the exercises was cumulative[16].
- The requirements for the post class assignment and the content of the presentation to be made in Module 13 were given both in writing and verbally, as the class progressed. The students learned about requirements traceability matrices and were advised to use an assignment requirements traceability matrix to ensure that their assignments are complete.

The delivery and the results in the classroom

The course was first delivered in Cranfield University to eight students commencing their Engineering Doctorate program in November 2007. The course was also delivered to 50 students at the National University of Singapore (NUS) in January and 13 in May 2008. The NUS students were mature students in the workplace taking the course for continuing education purposes.

Written anonymous daily feedback was solicited at the end of each day with the following four questions:

- Best - What was the best thing about the day?
- Worst - What was the worst thing about the day?
- Missing - What was something that you expected but was missing?
- Question - Was there a question that you failed to ask, or have since thought of and

[16] Information for previous modules is to be used in all exercises.

would like answered in the morning?

The responses were processed and shared with the students on the following morning before the day's modules began.

Results in the classroom

In all three delivery instances, the students were initially not prepared for the intense immersion format of the course. They arrived on the first day expecting the usual lecture format. They took a while to get used to the style and format of the course, but by the end of the third day, they became familiar with what was expected of them.

A subjective observation was made by Prof Kasser comparing the presentations in these courses, to students in traditional format (mostly lecture) classes on systems engineering he had taught at UMUC and UniSA. The student presentations in both Cranfield University and NUS in these courses on Day 2 were better than those of the traditionally taught students on the last day of their classes.

Student comments on the course. The student course evaluation survey contained 21 statements to which the students responded on a 5-point Likert scale. The responses for some of the statements on the NUS January 2008 course student evaluation forms are shown in Table 2. Responses to the same statements in the Cranfield University and NUS May 2008 course student evaluations were similar. The sample size at Cranfield was too small for meaningful conclusions other than they tend to support the findings at NUS.

Table 2 Responses from May 2008 Student Evaluation forms

STATEMENT	AVERAGE	STDEV	MEDIAN
The group exercises were excellent	3.8	0.7	4
The ratio of lecture to group exercises was just right	3.1	1.0	3
The course met my expectations	3.5	1.0	4
I would recommend this course to my colleagues	3.6	1.0	4
Other courses should use a similar ratio of lecture to exercise	3.1	0.9	3

The students were asked to comment on the pedagogy, administration and instructor in the course evaluation forms. While the best thing about the course was selected by a majority to be its hands-on format, the worst thing was its hectic schedule.

The students were also asked to state the three most important topics they learnt in the course. The topics with the most number of selections were the following templates/mnemonics

- ORP – observations, risks, problem template for sorting out the problem in a given situation.
- FRAT- functions, requirements, answers and tests template for designing an answer to the problem based on a modification of (Mar and Morais 2002).
- SPARKS - schedules, products, activities, resources, risks, and the relationships between the previous items mnemonic.

Presentation skills were the next most important topic.

The students were also asked to state the least useful topic. Most students responded with a “nil”, “nothing”, a blank or equivalent.

Six month NUS follow up

Six months after the course conducted at the NUS in January 2008, a selection of the students who were mostly practising systems engineers were asked to provide feedback on whether the course was effective for them, and how it helped them to apply the knowledge gained from the course to their work. The students were aware of the expectation by their employers to apply the learning from the course to their workplace. They were also aware that the course provided an understanding of how to map the learning to their employers' processes, but admitted that it was challenging to make changes to their work processes and it would take time to do so gradually[17].

Unconventional teaching methods

The teaching methods employed in the course were radically different from the lecture-based format typically used in local schools and tertiary institutions. With presentation slides and symposium papers as the main course material, the students were not accustomed to the lack of a “core text” book. As the unconventional delivery method of the course was not explicitly made known to the students beforehand, the students felt that they were not “mentally prepared” and thus were unable to fully appreciate and maximise their learning experience from the course.

The value of the course compared to more traditional formats, was yet to be clear to the students. They discovered in hindsight that they could find in textbooks the required information to manage the simulated project work. Thus, even though the reasons for the pedagogy (the learning pyramid, etc.) had been explained in the initial module, they could not fully understand the reasons for the unconventional teaching methods when textbooks seemed sufficient[18].

Experience levels

Students with inadequate working experience found the concepts insufficiently elaborated during lectures and the pace of group work too fast to “internalise” concepts[19]. On the other hand, students who had many years of working experience and were already applying systems engineering concepts in their daily work, did not feel that they benefited significantly from the course. This was because they were already practising the concepts presented in the course, in one form or another[20].

In the six-month feedback from the students, it was suggested that the immersion course would be effective for intermediate employees with 2-5 years experience, when they have become familiar with technical tools and are ready to solve large-scale engineering problems.

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[17] This finding is not unique to this situation.

[18] The declarative and procedural knowledge is indeed in the textbooks, but the conditional knowledge is obtained in the exercise and that needs to be conveyed to the students in a better way.

[19] A prerequisite of some systems engineering and project experience was set, but not adhered with in placing students in the class.

[20] This finding was also true in the traditional lecture-centric courses.

Intensity of the course schedule

Another feedback from students was that the course schedule may have been too intense, and they were feeling exhausted after each day of the course[21]. The students acknowledged that the simulated project work was a positive experience, but the stressful schedule may have affected their retention of the learning from the course.

Socio-cultural factors

The socio-cultural environment is an influential factor on a course consisting of numerous activities requiring interaction and cooperation among students. It had been observed that Singaporeans involved in systems engineering were generally more reserved compared to their western counterparts, and were thus less likely to initiate or spontaneously participate in discussions within unfamiliar groups of people. Indeed, the students had to be prompted to enter a dialogue with the instructor.

Lessons learned

The lessons learned from the Cranfield and NUS sections are documented herein using the ORP template as taught to the students in the course. The lessons learned from delivering the course include:

Observations

In no specific order, the observations are:

- Students may not be asking the necessary questions. In the presentations in Module 13 one team at NUS produced a system which was not compliant to instructions (requirements) as a result of a lack of communication. The systems engineering was good, however the project failed.
- Students tend to focus on incremental improvements to prior knowledge. This was evident in the different approaches in the NUS presentations, and even though they were encouraged to copy good techniques used by other teams, most took a while to do so.
- Students can be resistant to instructions. The Cranfield University students were told about ORP but had a tendency not to use it. Consequently, the module was modified to provide an ORP template in the lecture component at NUS, and it was then used by the NUS students appropriately. The Cranfield University students misunderstood one part of the SPARKS mnemonic as demonstrated by their presentations in the final Module. This misunderstanding was corrected in the discussion after the presentations22, but the misunderstood interpretation remained uncorrected in the student assignments.
- While the sample size was small, it appeared that the Cranfield University students who used the requirements traceability matrix for their assignment, as instructed in Module 7, tended to do better than students who did not use it. In addition, the students were advised that they could discuss the assignment with the instructor for up to three weeks following the class, but none did so23.

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[21] A standard problem with the intensive block-mode format.

[22] At last the instructor thought he had corrected it.

[23] This is also not unique to this course. Students in traditional courses at UniSA also did not avail themselves of similar opportunities.

- There are three types of systems engineers based on the ability to deal with vagueness as mentioned above. The format of this course allows the instructor to observe these characteristics in the students during the exercises. Serendipitous? Perhaps, but the experience in designing the DSTO Continuing Educational Initiative (CEI) may have influenced the design of the course, since one of the early purposes of the DSTO CEI was to identify students who were potential PhD candidates while they were studying towards a Master's by coursework degree.

Risks

In any teaming environment, there is always a risk of weak teams. The requirements imposed on the teams would usually work, but not in the case of one team in this course.

Problems

The unpreparedness of the students for the intense immersion format is a major issue.

The number of students needed to be set to provide a variety of presentations, yet minimise the time spent in presentations even though the presentations provide learning opportunities.

Summary

This paper has discussed the need for, the development, the delivery and the classroom results (four-day block delivery mode) of the world's first immersion course in systems engineering.

Conclusions

The immersion course format has produced better results in the university classroom than previous lecture-centric classes in the intensive block mode format. Some fine tuning still remains to be done. So its success in other delivery formats and in the commercial in-house world is yet to be determined.

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Biographies

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