Integrated Multidisciplinary Engineering for the 21st Century: Study Guide

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Development of this course was made possible by a grant from The Leverhulme Trust to Cranfield University.

Why this course

The purpose of this course is to begin the process of providing industry and government with a pool of skilled personnel for the acquisition and maintenance of the systems that underpin 21st century civilization. This is an introductory course proving an overview of the topic and a flavour of the details which should be more fully explored in depth through other courses. As you read these notes you will see that this course is very different to similar introductory courses. This is because the course was systems engineered by determining the needs of the stakeholders (employers (industry/government), students and academia) and then applying modern educational methodologies with some principles from cognitive psychology to the problem of providing an effective learning opportunity to mature students who are employed in the work force with corresponding demands on their time. In addition, unlike current similar courses, this course views systems engineering from the problem solving perspective. Detailed information about the design and implementation of the course is provided at the end of the document starting on page 20.

Description

The course introduces multidisciplinary and systems engineering and the need for their application from the problem solving perspective. The focus of the course is on:

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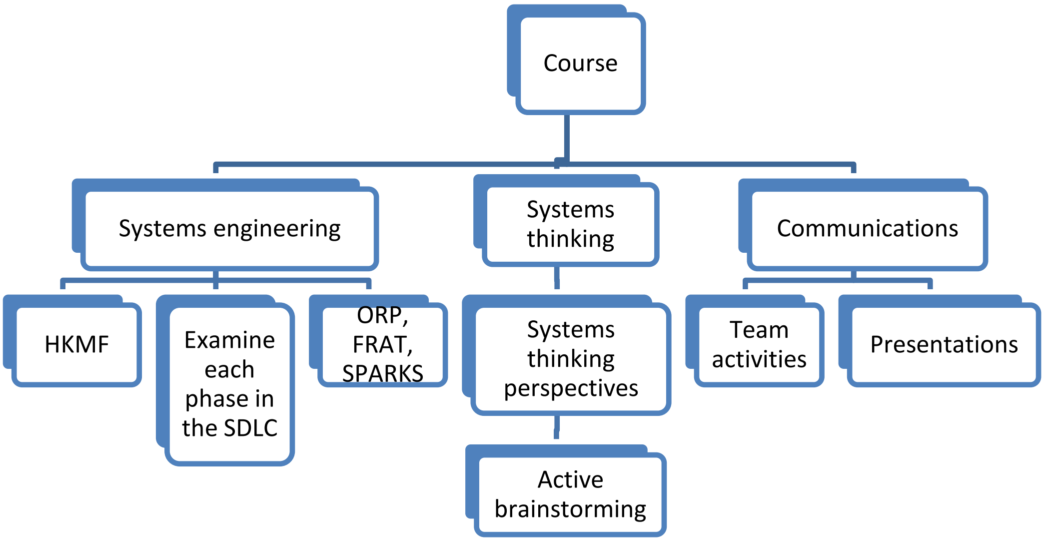

Figure 1 Structure of the course

- systems engineering,
- the application of systems thinking, and
- interpersonal communications.

The structure of the course showing the linkage between these elements is provided in Figure 1[1]. Providing a broad overview, the context for systems engineering, the competencies needed to perform systems engineering and the lifecycles employed are discussed. The application and measurement of systems thinking in the various phases of the project lifecycle is employed in practical exercises. The course employs problem based learning to enhance the learning experience.

Outcomes

At the end of this course, participants should:

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

Course modules

The course contains the following modules:

[1] The terms HKMF, ORP, FRAT, active brainstorming and systems thinking perspectives are explained in their context in the descriptions of the modules.

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1. An introduction to the design and construction of the course, followed by 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 operations and maintenance phases of the system lifecycle
12. Modelling, simulation and other methodologies, tools and techniques for systems engineering
13. Wrap up and Student presentations

The relationship between the modules is shown in Figure 2. The course is divided into four parts as follows:

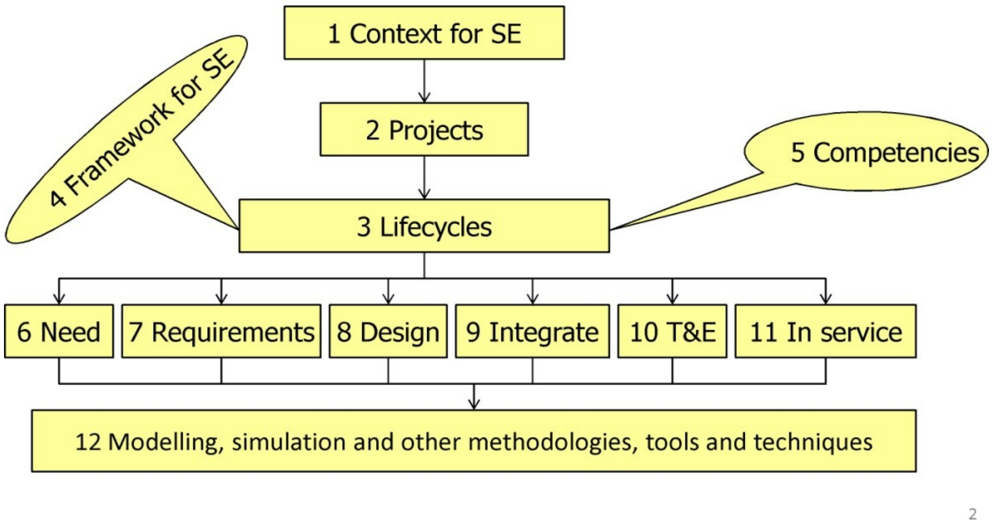

Figure 2 Relationship between course modules

- Part 1 begins with Module 1 which provides an iintroduction to the design and construction of the course, the contextual background to multidisciplinary engineering, systems engineers and systems engineering. Since systems engineering is generally performed in projects, Module 2 discusses the reasons for why projects fail and the lessons to be learned from those failures. Projects 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 for systems engineering by showing where and how it 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,

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- 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.
- 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.

Text book and readings

Text book

Kasser J.E., *A Framework for Understanding Systems Engineering*, produced by The Right Requirement Ltd and published by Booksurge, 2007; available from Amazon.com.

Pre course readings

The purpose of the pre course readings is to provide the students with an understanding of the skills they will be learning and how they will be assessed. The pre course readings are:

1. This Study Guide – providing the context for the course.
2. Wolcott, S. K. and C. J. Gray, "*Assessing and Developing Critical Thinking Skills*," Assessment Institute, Indianapolis, 2003 – providing the context for measuring the degree of systems thinking.
3. (Kasser, 1995b) – Perspectives on documentation and the documentation producing process to help the student understand the reasons for the exercise format.

In course readings

In order to expedite the exercises, in most instances, PowerPoint presentations summarizing the chapters in the text book will be provided in the course notes for all members of the team to review.

The perusing of the actual readings associated with each module is to be split between the members of the teams.

While the team as a whole is expected to have the knowledge in the readings, it is the responsibility of the team to split the readings amongst themselves and share the knowledge during the exercises.

Students taking the course for credit and doing the assignment will have time to read the entire set of reading while working on the assignment. For further details see page 24.

Team Exercises

The purpose of the exercises is:

1. to practice systems engineering, and problem solving,
2. to understand the scope of multidisciplinary and interdisciplinary engineering,

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3. to enable the students to grow intellectually and deal with ambiguity and complexity.
4. to learn about systems engineering by doing systems engineering, and
5. 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:
   a. Those needed in several if not all phases of the system life cycle.
   b. Those needed in specific phases of the system life cycle.
   c. Knowledge in the domain in which the system being developed/ maintained/ upgraded exists or will exist.

Unless otherwise stated, the teamwork components of the course will be split into the following two team exercises in each module[2]:

- Project Sukumu exercise.
- Staffing exercise.

The students are expected to manage their time with the assistance of the instructor. They can choose to do the exercises in series or in parallel. This section describes the context behind the exercises; details of the activity in each module are given in each module.

Exercise context

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

Table 1 Federated Aerospace's current projects

Project	Phase in the SDLC	Application Domain	Details on Page
Project Nemesis	Needs	Ship acquisition	19
Project Radiator	Requirements	Aerospace	19
Project Darwin	Design	Database (online transaction system)	20
Project Terminal	T&E	Information Technology	20
Project Octopus	In service	Transportation	20

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 (See context details and photographs starting on page 15). 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.

By some fortuitous coincidence, 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[3].

Link between module knowledge component and exercises

The link between the knowledge component (lecture and readings) and the exercises for each module is as shown in Figure 3. The lecture and readings cover the activities performed by

[2] 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. The post exercise discussions will be facilitated along this theme to draw out the reasons for their choices.
[3] The first letter of the project name reflects the phase of the life cycle (memory aid).

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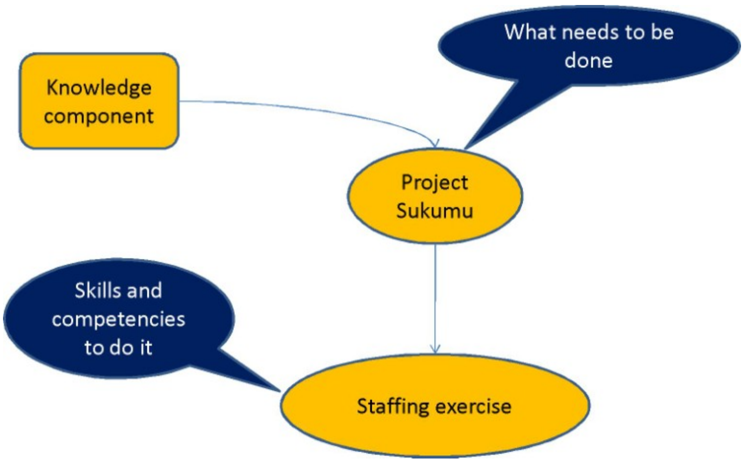

Figure 3 Link between knowledge component and exercises

systems engineers in general; 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 will present on a different project in a different domain in a different phase of the SDLC, the students will learn about problems, skills and competencies for different projects in different domains in different phases of the lifecycle.

The two projects not only complement each other but provide the students with the opportunity to progress through the SDLC for two very different types of system at the same time and reflect on the similarities and differences.

Project Sukumu exercise

This is a traditional class project. The students go through the SDLC process.

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:

- 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

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- 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 will be 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.

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 will be 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 will fill the test and evaluation function.

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.

Exercise activity

Each team will be associated with one of Federated Aerospace's current projects as described in Table 1 starting with Module 5.

Modules

This section contains details on the contents of each module.

Module 1. What are multidisciplinary engineering, interdisciplinary engineering, project management and systems engineering

Purpose To:

1. introduce the design and construction of the course,
2. provide an answer the question in the title of the Module,
3. identify the existence of confusion amongst systems engineers as to the

nature of systems engineering, and
4. understand the nature of the differences between systems engineering and project management.

Knowledge: Multidisciplinary engineering and systems engineering; a brief history of systems engineering and project management, the many different definitions of the word "system", the various viewpoints on systems engineering and a hypothesis for the reason why there are so many definitions.

Exercise: The students compare the definitions of systems engineering and group them to determine common denominators and determine support or refutation of the hypothesis.

Readings: Text book, Chapters 2, 11, 14 and 18.

Module 2. Why projects fail

Purpose: To provide the students with an understanding of the need to make use of lessons learned from past projects.

Knowledge: Projects, views of projects and project plans, risks and a number of lessons learned from high-tech project failures and successes.

Exercise: Each student team is to review the readings and prepare and present on the following two topics:

- Does the data support Donaldson and Seigel's reasons, and why?
- How could we detect and prevent failing projects?

Readings: Text book chapters 6, 10.8 and 19.3.

Course readings on Module 2.

Module 3. An introduction to lifecycles

Purpose: To:

1. Provide the students with the background for the activities performed by systems engineers in various stages of system development.
2. Explain the difference between systems, products, processes and lifecycles.

Knowledge: Introduction to the SDLC, project life cycles, various models of the lifecycle, systems engineering standards, architecture frameworks, project plans, the nature of changes during the lifecycle and the Functions, the Requirements, Answers and Test (FRAT) methodology.

Sukumu Exercise: Review the Sukumu Project data in the supplementary presentation and in the material starting on page 15. The students are to:

- Determine technological uncertainty of Project Sukumu implementation
- Pick and be prepared to defend the choice of lifecycle
- Define the system boundaries
- Consider the sub-systems, noting that the technological uncertainty may be different for different parts of the system.
- Note some of the risks (things that could go wrong) with the project, from Module 2 (and other appropriate sources).
- Prepare a draft work plan (project plan) template and fill in what they can.
- Provide a copy of the draft presentation to instructor at end of module. A presentation is not expected.

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Students are expected to save a copy of the draft presentation and compare it to the one they produce in Module 13 as a self evaluation of their progress.

Readings Textbook Chapters 3.3.10, 4.9, 4.10, 5, 12 and 17.1.

Course readings on Module 3 – (Kasser, 2008)

Module 4. A framework for understanding systems engineering

Purpose To introduce a framework for understanding systems engineering which provides an insight as to the reasons for the many definitions of, and viewpoints on systems engineering.

Knowledge The Hitchins-Kasser-Massie Framework (HKMF); maps the lifecycles discussed in Module 3 into the HKMF; explains the reasons for the overlap between project management and systems engineering.

Exercise The students, as a team will select one of the current Federated Aerospace's current projects. Each team of students will determine the nature of the different types of problems faced by systems engineers in the phase of Level 2 of the HKMF for the four levels of technological uncertainty associated with their project.

Readings Text book chapter 20, and recap chapters 11 and 18 from Module 1.

Module 5. The competencies of a systems engineer

Purpose To identify the qualities, knowledge and experience needed by junior, intermediate and advanced systems engineers in various phases of the system lifecycle.

Knowledge Provides an awareness of the factors involved in the role of the systems engineer in projects, systems thinking, critical thinking and active brainstorming; how to apply and measure systems thinking, the skills needed to perform those roles and the requirements for the competencies.

Staffing Exercise Using the ORP and FRAT, the students will map the skills, knowledge and experience requirements extracted from the lecture and readings components and external sources (with traceability), into the Layer 2 and Layer 3 areas of their current Federated Aerospace Project into the HKMF.

Readings Text book Chapter 9.

Course readings on Module 5 - (Kasser and Mackley, 2008), (Hudson, 2006; Frank, 2007), (Eichhorn, 2002) and (Kasser, 1995a). Read pages 1-9 and 33-36 of (Hudson, 2006) in this module, remainder of document is for use in subsequent modules. Recap the pre-course reading.

Module 6. Systems engineering in the needs definition phase of the system lifecycle

Purpose To identify the role of systems engineers in the needs definition phase of the system lifecycle, the nature of the problems they face, and introduce the tools, methodologies and techniques available to solve those problems.

Knowledge Provides an awareness of the context of the needs phase, business cases for project adoption.

Sukumu Excercise The students will update the project plan to show how they would deal with the following stakeholders:

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- Defence – need to move materiel by road between border crossing points and the barracks.
- Local industry – want air transport between Engaporium and the new resort area.
- Mining – want railways extended to ship more ore.
- Friendly neighbours – interested in building bridges across rivers to take advantage of the tourists.
- Government – wants to make as much income as is reasonable.

Staffing Exercise — The students will define the missing skills and competencies for their project SET using the resumes of the remaining SET members supplied by the instructor and perform a gap analysis with the information generated in Module 5. Presentation to be made at the end of the exercise.

Note — From this module onwards the students are expected to apply systems thinking and organise information in accordance with the systems thinking perspectives (STP) learned in the previous module.

Readings — Course readings on Module 7 (Kasser, J E., Case Study Presentation of C3I Operational Analysis Group Study, 2000).

Module 7. Systems engineering in the requirements phase of the system lifecycle

Purpose — To identify the role of systems engineers in the requirements elicitation and elucidation phases of the system lifecycle, the nature of the problems they face, and introduce the tools, methodologies and techniques available to solve those problems.

Knowledge — Provides an awareness of the factors involved in the types of problems faced in this phase of the system development life cycle, sources of requirements, the acceptance criteria, cost, risk, and priority properties of requirements, the importance of well-written requirements and some of the consequences of poorly written requirements.

Sukumu Exercise — The students will update their system configuration from that documented in Module 2. In addition they will update the project plan to cover

- How the system requirements will be developed.
- Where the system requirements will come from (traceability).
- A summary of the system requirements and the acceptance criteria, cost, risk, and priority properties.

Staffing Exercise — The students will define the requirements for the additional SET positions for their Project in the form of outline job descriptions covering knowledge, experience and other factors the team deems pertinent and define metrics for selection of applicants. Presentation to be made at the end of the exercise.

Readings — Text book chapters 10, 15 and 16.

Course readings on module 6 (Kasser and Mirchandani, 2005), (Hari, et al., 2006).

Module 8. Systems engineering in the design, construction and unit testing phases of the system lifecycle

Purpose — To identify the role of systems engineers in the design, construction and unit testing phases of the system lifecycle, the nature of the problems they face,

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	and introduce the tools, methodologies and techniques available to solve those problems.
Knowledge	Provides an awareness of the factors involved in functional and physical partitioning of a system, analysis for determination of feasibility, the three types of emergent properties, factors to consider and monitor in the design for performance, cost, reliability, integration, test, maintainability and safety and design optimisation or problem solving across subsystem boundaries.
Sukumu Exercise	The students will update their project plan with the details of producing two alterative system designs (architecture) and the factors that will affect the selection of an alternative.
Staffing Exercise	The students will use the applicant resumes provided by the instructor to: • Determine a short list of candidates to interview. • Design a number of SETS using different combinations of the candidates within the constraints of the staffing budget. The students should also plan for refusals and how to make use of overlapping skills within the SET. Presentation to be made at the end of the exercise.
Readings	Text book chapters 13 and 17. Course readings on Module 8 (McNamara, 1997; Arnold, 2006; Kasser, 2008).

Module 9. Systems engineering in the integration phase of the system lifecycle

Purpose	To identify the role of systems engineers in the integration phases of the system lifecycle, the nature of the problems they face, and introduce the tools, methodologies and techniques available to solve those problems.
Knowledge	Provides an awareness of the factors involved in integration of components into a system, integration of a system into its adjacent systems, design for integration and problem solving across subsystem boundaries, interface and change management.
Sukumu Exercise	With the approval of the instructor, the students will assume one of the options developed in Module 8 was chosen. They will then update the project plan to add an integration plan containing the details of integrating the subsystems into a system.
Staffing Exercise	After finding out which applicants have been interviewed and have accepted a position and when they will be joining the company, the students will plan how to integrate the additional members into the SET. The plan should also discuss new employee training about project and how the SET would cope with the missing skills. Presentation to be made at the end of the exercise.
Readings	Course reading on Module 9, presentation - Kasser J.E., "Systems Engineering Support of the Integration Management Process", INCOSE 2006.

Module 10. Systems engineering in the test and evaluation phase of the system lifecycle

Purpose	To identify the role of systems engineers in the test and evaluation (T&E) phases of the system lifecycle, the nature of the problems they face, and introduce the tools, methodologies and techniques available to solve those problems.

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Knowledge — Provides an awareness of the difference between test and evaluation, the need to build testing into the system and SDLC and the various factors involved in T&E.

Sukumu Exercise — The students will update their project plan with details of how the system will be tested and evaluated, namely a T&E plan.

Staffing Exercise — The students will verify and validate the new SET with traceability. In addition, mirroring the real world, the students will be informed that a candidate has withdrawn, and asked to recommend the appropriate action. Presentation to be made at the end of the exercise.

Readings — Text book chapter 8.

Module 11. Systems engineering in the operations and maintenance phase of the system lifecycle

Purpose — To identify the role of systems engineers in the handover transient, operations and maintenance phases of the system lifecycle, the nature of the problems they face, and introduce the tools, methodologies and techniques available to solve those problems.

Knowledge — Provides an awareness of the factors involved in changes and upgrades, teams, and control of phased sequential system releases.

Sukumu Exercise — The students will update their project plan with details of how the system will be handed over to the customer and how it should be operated and maintained by the customer.

Staffing Exercise — The students will describe how the new SET (mix of old and new employees) will function under conditions staff turnover. Instructor will provide information as to which specific members of the SET leave. Presentation to be made at the end of the exercise.

Readings — Text book, recap chapter 12 from Module 3, and chapter 13 from Module 8.

Course readings on Module 11, – Kasser, J.E., Program Management Methodology.

Module 12. Modelling, simulation and other methodologies, tools and techniques for systems engineering

Purpose — To discuss introduce models and simulations and the place and use of various tools and techniques to the areas in the HKMF.

Knowledge — Introduces modelling and simulation; discusses their place in the systems life cycle, nature and uses of models.

Sukumu Exercise — Students to refine project plan to incorporate changes due to information acquired in later modules especially with reference to the use of tools.

Readings — Course reading on module 12 (Martin, 1994).

Module 13. Wrap up and Student presentations

Purpose — To summarise and wrap up the course, and provide an opportunity to learn from the student presentations of their versions of the planned realisation of the Sukumu project and the differences between the approaches reinforcing the concept that generally there is more than one solution to a problem and

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	the correct solution is one which satisfies the customer.
Knowledge	The course wrap up, and post presentation discussion. If students are taking the course for credit, details of the assignments and method of assessing the assignments will be presented.
Exercise	The Sukumu project plan presentations complete the team exercise.
Readings	None.

Assignments and assessments

This section applies to students taking the course for academic credit towards a postgraduate award.

The staffing exercises in Units 6 to 12 will not be assessed, these are learning experiences and the students need to focus on the work rather than worry about being assessed. Assessment will be performed on:

1. Post course assignment
2. The Sukumu project final presentation in Unit 13.

Post course assignment

Each student being assessed is to flesh out their Sukumu project team presentation as an individually produced document. Details need to be added based on the spoken presentation, audience comments; contents of readings, lectures and external sources. A reflection component will be required for a high grade.

Grading criteria

The grading criteria are set to demonstrate critical thinking[4] (Wolcott and Gray, 2003) to the systems engineering process in the context of a project lifecycle and award points for how well a student demonstrates the ability to predict, diagnose, explain and solve non-textbook problems because most systems engineering problems are non-textbook problems.

Students taking the course for credit towards a postgraduate degree should achieve a Credit or better. Grades will be awarded according to the criteria shown in Table 2.

Table 2 Grading Criteria

Grade	Critical Thinking Level	Systems Engineering
Pass 2 (E)	Confused fact finder	Knows the systems engineering process and understands the relationship between systems engineering and projects
Pass 1 (D)	Biased jumper	Understands problems in context
Credit (C)	Perpetual analyser	Understands the systems engineering process
Distinction (B)	Pragmatic performer	Understands the need to tailor the process to fit the situation
High Distinction (A)	Strategic re-visioner	Ability to tailor process to situation

[4] In the academic context, critical thinking is becoming the application of systems thinking.

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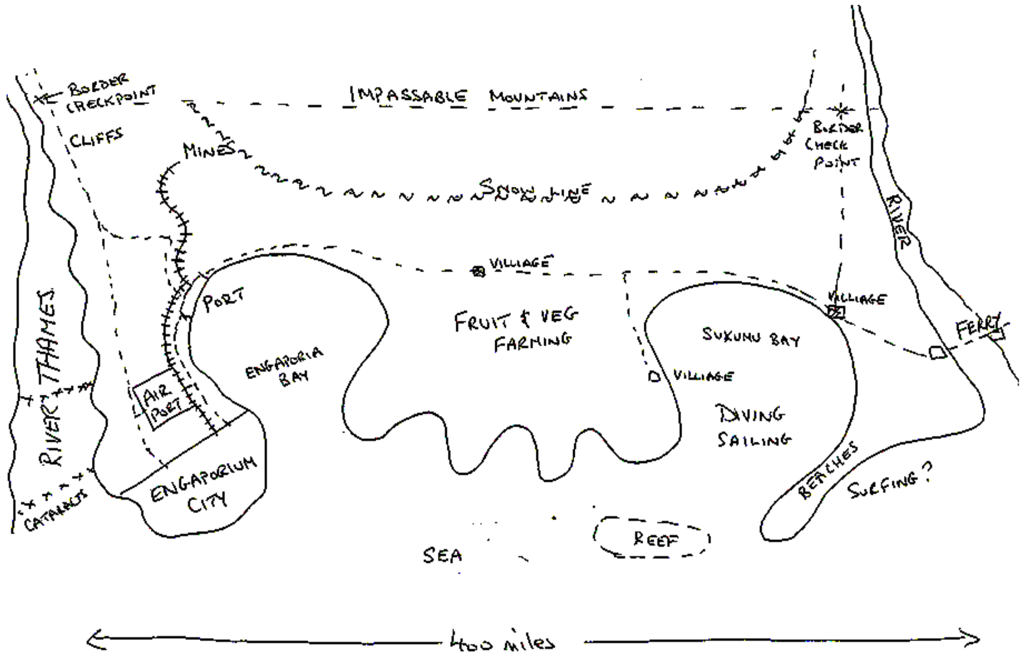

Figure 4 Engaporia

Engaporia

Engaporia is an old British colony, with a stable democratic government, and a small population. It is a non-aligned, mostly ignored member of the UN. It is located between sea and mountains as shown in the map in Figure 4. Other details are:

- A Mediterranean climate; the coastal plain having warm summers and mild winters.
- A mining and farming economy.
- A strategic port location, the Royal Navy used it as a naval base.
- The population is concentrated in Engaporium city.
- The government has recognised that the population is growing to the point where there will be an unemployment problem in near future.
- Impassable mountains to north which are snow covered in winter.
- A disputed border with northern neighbour.
- Unnavigatable (into the hinterland) rivers to east and west, although there is a ferry across the western river boundary.
- Friendly borders with eastern and western neighbours.

The existing infrastructure

- Airport with less than 5 flights per day
- Airport can just about cope with a 747-400
- Airport also used by defence forces
- Mineral ore shipped by rail to port then by sea
- Railway between Engaporium, airport, port and mines
- Port is ex-British navy base, modified for shipping mineral ore in bulk
- Roads (tracks) in hinterland
- Technology is colonial legacy

The context of the project

- Cost plus award incentive fee contract
- Four years
- Turnkey system
- Funding by international consortium of banks, hotels and resorts
- Revenue potential
    - Mineral wealth
    - Tourism
    - Winter sports and all year round unpolluted beaches
    - Casino, new resorts, cruise ships, tax free shopping
- Tourism facilities to be developed in parallel with the Sukumu project
    - Casino
    - All season beach hotels and activity areas
    - Two ski resorts along foothills
        - Engaporium and eastern end of country
- Reef stabilisation to protect recreation in Sukumu Bay
- Port upgrade for cruise ships

The proposal promised

- A feasibility study
- Consultation with customer
- Development of integrated transportation system
- Phased approach
- Handover to local personnel for operations and maintenance

Photographs of Engaporia

To provide a flavor of the country, and the reason why the staff are flocking to join the project, some of the photographs taken by the Federated Aerospace proposal team during their site survey are shown below.

Lift up thine eyes to the hills

Development of this course was made possible by a grant from The Leverhulme Trust to Cranfield University.

Snow covered mountains and river seen from the East as they flew into the country.

Thames estuary showing narrowness of land at sea level.

Unspoiled beaches

Development of this course was made possible by a grant from The Leverhulme Trust to Cranfield University.

Waiting for the tourists

Farming

Typical roads

Development of this course was made possible by a grant from The Leverhulme Trust to Cranfield University.

Engaporium

The downside

Federated Aerospace's current projects

This section contains details of Federated Aerospace's current projects. Should a student team wish to change the domain of their project, but not the phase, for an alternative domain to reflect their workplace, they may do so with the approval of the instructor. Background details in the form of PowerPoint presentations will be provided to the students at the beginning of the course.

Project Nemesis

Project Nemesis is the construction of a set of four ships or boats[5]. A capability gap analysis has shown that there is a need for additional naval capability. This project is in its needs phase. Unfortunately several key members of the project team are defecting to the Sukumu Project and the gap needs to be filled.

Project Radiator

[5] The choice of surface or submarine will be discussed with the students who will make the decision.

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Project Radiator is the development of a single stage to orbit spacecraft to lift four people and a limited amount of equipment to provide space capability to nations wishing to acquire it independent of the USA, Europe and Russia. The Radiator spacecraft will dock with unmanned launchers and the international space station. This project is in its requirements phase.

Project Radiator has developed as set of operational scenarios for normal missions and contingency situations. The customer has agreed with the concepts and the requirements documentation process has begun. Unfortunately several key members of the project team are defecting to the Sukumu Project and the gap needs to be filled,

Project Darwin

Project Darwin is the design, construction and installation of a new student enrollment and course tracking system (SECTS) for Hypothetical University (HU). This project is in its design phase.

HU is experiencing problems with the SECTS used by students to enroll and track their courses. With the manual registration process currently in use, the load of paper work imposed on the HU's staff and its faculty is tremendous. Project Darwin has developed the operations concept and written the Requirements Document for the new system. The customer has accepted the requirements and the design process has begun. Unfortunately several key members of the project team are defecting to the Sukumu Project and the gap needs to be filled.

Project Terminal

Project Terminal is the development of a management information system for the National Mining and Development Corporation. This project is in the T&E phase. Unfortunately several key members of the project team are defecting to the Sukumu Project and the gap needs to be filled.

Project Octopus

Project Octopus is the upgrade of a city transportation system (standard bus, rail, and dial-a-ride). Federated Aerospace performs the upgrades, while another contractor performs the actual operation of the transportation system. The system has been in operation for years and the process of periodic upgrades is ongoing. Unfortunately several key members of the project team are defecting to the Sukumu Project and the gap needs to be filled.

Details of the construction of the course

This course is different to other current courses in systems engineering which focus on the knowledge component and tend to be lecture-centric. This section provides background information pertaining to the design of the course, and the reasons why it is different to other introductory courses in the topic (Kasser, et al., 2004; Kasser, et al., 2005). The design process is shown in Figure 5. This section discusses:

- The stakeholder needs.
- The Assumptions underlying the design of the course.

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- The courseware modules.
- The pedagogy of the course.

The stakeholder needs

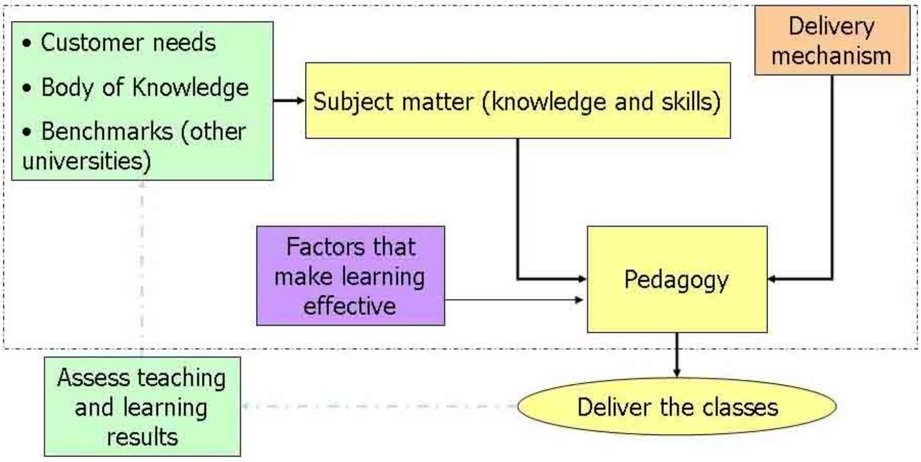

Figure 5 Process for crafting a course

The needs[6], grouped by stakeholders (employers, students and academia), are summarized as follows:

Employers (industry and government)

1. To be near the top of the of the value chain in the new global economy.
2. A pool of skilled personnel for the acquisition and maintenance of the systems that underpin 21st century civilization.
3. Competent[7], 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.
4. Coursework is not to 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.
5. Knowledge, skills and competencies, that are useful immediately, and in the short and long terms.
6. Ability to communicate systems engineering principles to others.
7. 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.
8. Engineers who are effective at solving open-ended problems (Durward K. Sobek II and Jain, 2004).

[6] These are needs, not requirements, and consequently are not shown in the format of requirements.
[7] Systems thinking has been identified as a key skill.

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Students

1. Enhanced career opportunities[8].
2. Study workload that is appropriate to the lifestyle of a full-time employee with a family.
3. An understanding of what systems engineering is all about and why every system engineer describes it differently.
4. An understanding of how what has been learnt in the class maps into their employer's processes.
5. A course experienced in a manner that makes learning effective.
6. Affordable text books[9].
7. A clear understanding of how their work in the course will be assessed[10].

Academia

1. A marketable course.
2. A teachable course in the traditional semester mode, as well as online using both full-time and part time instructors.
3. Contain components that can easily be incorporated in existing engineering and information technology courses.

Assumptions underlying the design of the course

The course has been designed based on the following assumptions

1. A single course cannot meet the all the needs of the industrial and government stakeholders.
2. This class is not one in which the students do in-depth systems engineering, this is an introductory "breadth" class which examines systems engineering from various perspectives in accordance with (Kasser and Palmer, 2005). The assumption is that students will continue their studies and take "depth" classes in requirements, test and evaluation, etc. in which they will apply systems engineering to traditional technical systems in the appropriate phases of the lifecycle.
3. As a prerequisite to taking this course, students will have at least a rudimentary knowledge of mathematics, systems engineering and project management.
4. Each Knowledge Unit is a "breadth" unit; references will be provided to the students for in-depth study during the assignment and after the course is completed.
5. The knowledge for this course comes from the lectures, the readings and the exercises.

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[8] 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.

[9] Experience with post graduate students at The George Washington University (GWU), University of Maryland University College (UMUC) and the University of South Australia (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. Since some students have to pay for the books even though they get their tuition refunded, they get annoyed when listed text books are not fully used and complain to the program director. In addition, having been burned that way myself at GWU by an instructor exercising his academic freedom not to use the expensive listed text books, when I was a postgraduate student, I quickly learned never 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. This also meant that I didn't get the books until the second or third session.

[10] 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 by UniSA. The students perceive that the grades have an influence on their future in the organization.

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6. Students are expected to review the readings before doing the in-class exercises[11]. Time will be allocated for reviewing the readings during the exercises.
7. Students are expected to put in additional out of class hours on their studies. The anticipated workload should be no greater than the amount of effort postgraduate students put into earlier projects at University of Maryland University College projects, see (Kasser and Williams, 1999; Kasser, 2001b, a).

Courseware modules

This course contains 13 modules containing the following components

1. A set of PowerPoint slides for a lecture.
2. The accompanying instructor's notes for what knowledge to highlight during the lecture.
3. Exercises – accompanied by suggestions of what to do, what to expect the students to produce and how to assess the results.
4. Summaries of the readings to use when discussing the exercises with the students during the classroom exercises.
5. 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 will be provided to the students.

Design goals for the courseware components

The design goals for these components are:

1. The components should be designed to ensure the students need to use and hence develop systems thinking skills.
2. Each module should be split into three one-hour sessions with a short break between them.
3. The lecture component should be no more than 45 minutes, preferably in two 15 minute sessions with the remainder of the time used in a facilitated discussion.
4. The lectures should supplement the readings discussing their contents at a high level rather than contain the same content as the readings.
5. When possible in semester mode delivery formats the students (as individuals or groups) should be asked to deliver the lecture components in units 6 to 11 for a portion of their grade[12,13,14].
6. The remaining two sessions in the module should be devoted to students working together in teams in a problem based learning environment[14].
7. The team exercises should be set within a single context. This will minimize the time the students spend becoming familiar with the context before actually performing the exercise.
8. Each team should work on the same project independent of the others. This is to allow comparisons of approaches to demonstrate that there need not be one "right" solution.

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[11] This was done effectively in the "Systems Engineering for Complex Problem Solving" course delivered to DSTO at UniSA in 2006/2007.

[12] I have done this in semester mode postgraduate classes in Computer systems Management and Software Engineering at UMUC and it worked out quite well.

[13] Having two lecture components in a unit means (1) more than one student can give a lecture in a class, and (2) that the length of the lecture is short enough so that the attention spans of the students are not exceeded.

[14] This is in accordance with (1) modern pedagogy which states that listening and reading are the worst ways to retain information while doing and teaching are the best, and (2) the need for systems engineers to be able to work together in teams.

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9. Ideally teams should be composed of at least one male, one female, one experienced, one novice and one in possession of a laptop computer (for the presentations). In an open class, students from different organizations and national cultures should be mixed into teams. One person may meet more than one of the criteria.
10. Students should be given the opportunity to choose who they would like to team with, and who they would not like to team with, and the instructor should try to meet their wishes providing the guidelines for membership can be complied with.
11. Each team exercise should terminate with a presentation. After the students have presented their work, the similarities and differences of the student team's presentations will be discussed.
12. (Wolcott and Gray, 2003) 's method of assessment is similar to (Biggs, 1999)'s criteria for assessing the degree of deep learning successfully used in a modified manner at UniSA. Hence, the exercises and post course assignment will be designed to ensure the students need to use and hence develop critical thinking in accordance with the five steps published by (Wolcott and Gray, 2003) and the systems thinking perspectives described in the course notes.

The pedagogy of the course

The course is designed to use active learning in accordance with the Learning Pyramid and the earlier Dale cone (Dale, 1954) redrawn as shown in Figure 6. 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.

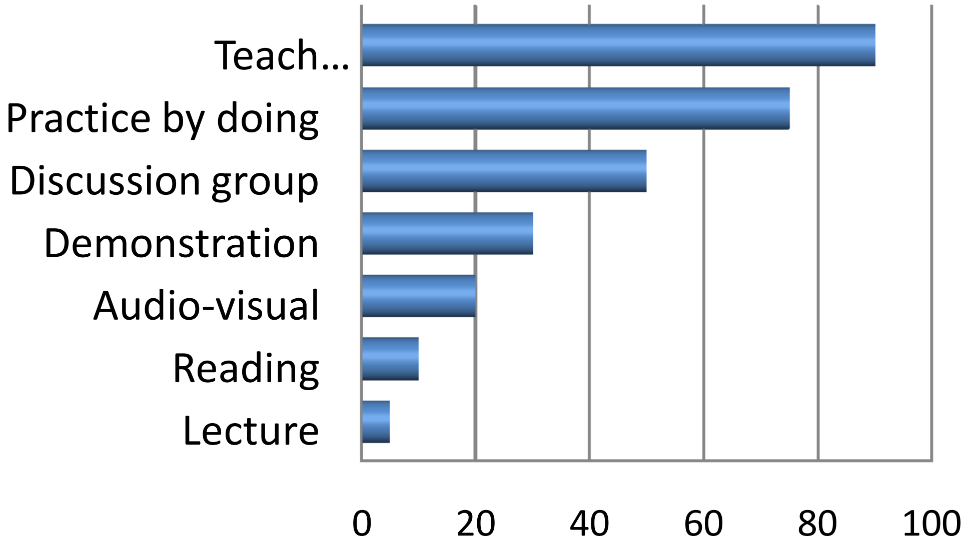

Figure 6 Retention of knowledge after two weeks based on the Learning Pyramid

Learning takes place using the following sources:

- **Lecture** - each module contains a short lecture to set the context.
- **Readings** – these supplement the lecture and provide other information. During the team exercise, the students divide the readings and each reads a part. This serves two purposes. The primary purpose is the knowledge in the readings, the secondary purpose is for the students to each become 'experts' in what they read, and bring that expertise to the team emulating the real world of multidisciplinary teams when they will have to deal with subject matter experts and develop a trust of their level of competency.

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- **Practical activity** – these are problem based learning scenarios. The team members contribute their prior knowledge and construct learning.
- **External sources** – these are any pertinent sources the students may choose to contribute. There is a wide body of literature out there and the sources of learning should not be limited to those provided in the course.

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