Systems Engineering in the Conceptual Stage:

A Teaching Case Study

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Abstract. Teaching examples in systems engineering tend to fail to illustrate the conceptual problem-solving early stages in systems engineering. This paper provides an illustration by using the example of tackling the problem of providing postgraduate students with an optimal learning environment as an example of factors to be considered in the conceptual early stages of systems engineering, how the seeds of doom can be planted into a project in the early stages and how recursion and iteration are invoked in the systems engineering process. Questions and comments are provided in the text, in footnotes and in an afterword to facilitate discussion in class.

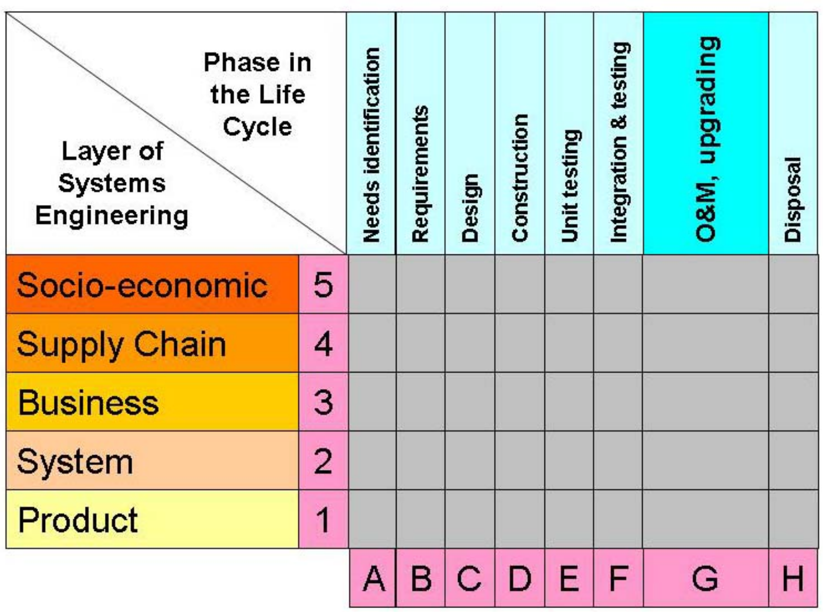

Figure 1 The HKM Framework for understanding systems engineering

[1] Author's names are given in accordance to their cultural naming order. Family names are capitalized for easy identification in accordance with Conference Country convention.

Background

The scope of the activities discussed in this paper are limited to the 'identification of need' phase in the Hitchins-Kasser-Massey framework (HKMF) (See Figure 1) for understanding systems engineering (Kasser, 2007a) particularly the activities performed in column A.2 (Kasser, et al., 2009) of the HKMF[2].

The paper begins by stating a need[3] and then describes a systems engineering approach to tackling a problem (Hitchins, 2007) using the stated need as a starting point. The stated need is that of providing postgraduate students in systems engineering with an optimal classroom teaching and learning environment, namely a system[4]. The paper then demonstrates the development of conceptual alternative solutions to meeting the need by introducing and considers a sampling of the factors that affect the solutions. Sketchy concepts of the solutions are shown, discussed and a few representative risks associated with the solutions are identified. The paper then describes the development of a set of evaluation criteria and illustrates an example of decision making in a situation where the choice is unclear and more information is needed[5]. Having identified the conceptual solution the paper moves on to discuss the formulation of strategies and plans for implementing the solution system. The recursiveness of systems engineering is discussed at this point. However, instead of exiting the process block at this point, the need for iteration is introduced because new information is presented. The effect of iteration and

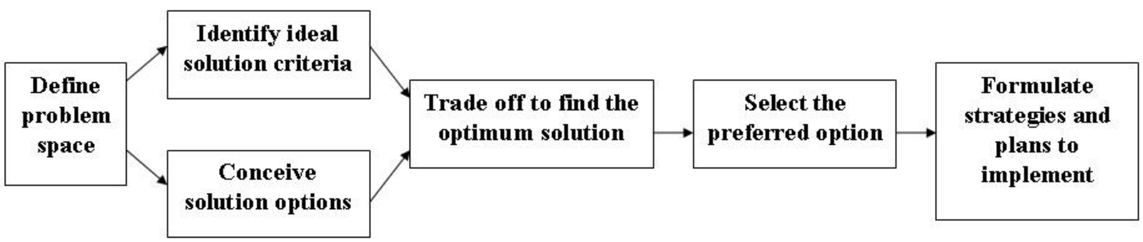

Figure 2 A systems engineering approach to problem solving (Hitchins 2007, Figure 6.2)

[2] Column A addresses the conceptual solution and comprises the following sub-phases:

1. This sub-phase contains the set of activities that explore/scope the problem, leading directly to...
2. This sub-phase contains the set of activities that conceive the whole solution system (which 'emerges' from/"complements" the problem) and produces the concept of operations (CONOPS) which describes how the solution system will operate in its future environment.
3. This sub-phase contains the set of activities that design the whole solution system, identify the environment, other interacting systems, the subsystems, parts, interactions, functional architecture, physical architecture, etc., etc., - but still all of the whole.

[3] Notice the need was stated not explored. Is this a common occurrence?

[4] There are at least two unstated and/or implied constraints or assumptions in this situation, these being that:

- The solution system is limited to the classroom environment and online distance mode and other non-traditional options are out of scope.
- The content of the course meets the requirements for the knowledge components.

Unstated and/or implied constraints or assumptions can have a great deal of influence on the solution system often planting the seeds of doom which lead to realisation of the wrong solution system.

how to show it on the schedule and cost is then discussed. Throughout the discussion, the factors affecting the solution in the educational environment should be considered as representative, not complete. These factors are only provided for the purposes of providing an example of systems engineering in columns A.1 and A.2 of the HKMF as discussed in the paper.

A systems engineering approach to tackling a problem is shown in Figure 2 (Hitchins, 2007) page 173). The approach contains the following six Tasks:

- Task 1: Define the problem.
- Task 2: Conceive alternative solution options.
- Task 3: Identify ideal solution evaluation criteria.
- Task 4: Perform trade off to find the optimum solution
- Task 5: Select the preferred option
- Task 6: Formulate strategies and plans to implement the preferred option.

Setting the context, in this specific implementation of the approach, the activities performed in Task 1 take place in Column A.1 of the HKMF (Kasser, et al., 2009), while the activities performed in Tasks 2 – 6 take place in column A.2.

Task 1 Defining the Problem Space

The first task in the systems engineering approach to tackling a problem shown in Figure 2 (Hitchins, 2007) page 173) is to first define the problem space. If the problem can be expressed as a needed function, the solution becomes a system that performs the needed function namely the solution is the inverse of the problem[6]. In this case, the customer stated the problem[7] as the need to provide postgraduate students studying systems engineering in a classroom[8] with the necessary knowledge and skills components in an optimal manner and the target optimal solution is a system in the form of a classroom that provides postgraduate students studying systems engineering with the necessary knowledge and skills components in the optimal manner[9]. The optimal manner is defined in this situation as the best way which allows the students to ingest, retain, understand and be able to apply the required amount of knowledge in the time allocated to learning[10]. The customer also stated that factors affecting the solution shall include the realisation

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[5] Commonly known as operating under conditions of uncertainty.

[6] Similarly if the problem can be stated as a function that is present but not needed, then the solution becomes a system that no longer performs the function.

[7] The Task 1 activities that convert the need to a problem statement take place in column A.1 of the HKMF; hence the starting point for column A.1 should have been a statement of the need, not a statement of the problem. Does starting with a statement of the problem imply that the activities which should have been performed in column A.1 were in fact not performed?

[8] This is an example of how unchallenged assumptions can lead to poor solutions. For example, challenging the assumption, one could ask is it self-evident that the solution consists of a classroom? Could it be instead, a learning laboratory, an online environment or some other alternative? Is it possible that the root problem has yet to be identified? And does 'using a classroom' preclude learning in an optimal manner?

[9] This may also be an example in which the customer states the problem in solution language.

[10] Is this definition valid? Surely, the value of a systems engineering course can be judged only by outcome, that is by the quality of the students, perhaps 3 or 4 years down the road, when they have jobs in the business and they can look back and reasonably determine what the course gave them that has proved useful. So, outcome is more valuable than output.

that postgraduate students are generally employed full-time, studying part-time, and have families and other demands on their time. Consequently, the time they can allocate to their education is limited, hence the need to optimize the learning experience (Kasser, et al., 2004). At the same time, the most commonly used method for transferring knowledge[11] from the instructor to the student still seems to be the lecture-based approach.

The next pair of tasks in the systems engineering approach to tackling a problem may be performed in parallel. They are the tasks which conceptualize alternative solutions and identify ideal criteria for evaluating solutions.

Task 2 Conceive Conceptual Solution Options

A conceptual solution is one that provides a complete solution to the whole problem. Consequently, it is essential to delineate the *whole* problem first and then show that the conceptual solution would solve, resolve or dissolve that *whole* problem. Conceptualising solutions takes the form of visualising two or more conceptual solutions. The conceptual solutions can be adaptive, namely minor or incremental changes to an existing system or situation, or the conceptual solutions can be innovative (Kirton, 1994) but either way they shall solve, resolve or dissolve the *whole* problem. One process of identifying potential candidate solutions takes the form of asking questions about the problem and potential solutions from each of nine systems thinking perspectives using active brainstorming (Kasser, 2009a).

The context for the problem/solution in this situation is a classroom[12] which can be expressed as a system containing the professor, and the students. Moreover, the students can be arranged in groups or teams as shown in Figure 3. Two sets of

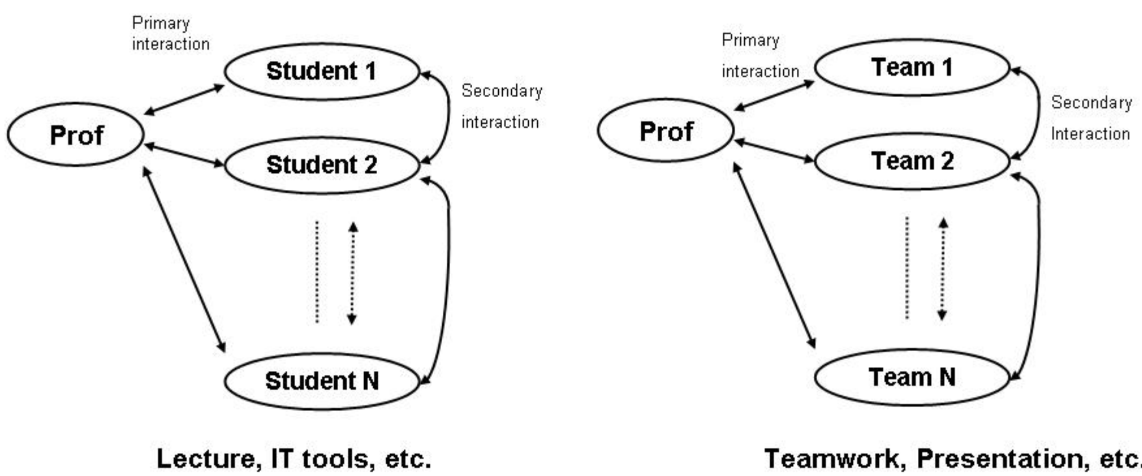

Figure 3 Two of the relationships in the instructor-based classroom system

[11] Knowledge or understanding? What is the difference?
[12] The classroom context has been insisted by the customer. In this case it demonstrates a real-world situation in which the seeds of doom (providing the wrong solution) can be planted into the project by poor very early stage systems engineering.

interactions take place in the system[13], the primary interaction being communications between the professor and the students, and the secondary interaction being communications between the students and the students. For simplicity the secondary actions are only shown between two student/teams, in reality there is interaction between each student/team and all the other student/teams.

Three candidate conceptual solutions were identified from processing the following questions[14].

- Operational perspective. The following questions were posed.
    1. *What is the current approach?*
    2. *How can it be improved?*
- Generic perspective. The following questions were posed.
    1. *What does the literature have to say about more effective ways of teaching and learning?*
    2. *What lessons can be learned from other people's teaching/learning experiences?*
    3. *How can those lessons learned be used to solve this problem*?
    4. *What is this problem similar to*?

The answers were not readily apparent so a review of the literature in the education domain was undertaken, a process of systems engineering research in the manner described by (Hall, 1962)[15]. This research produced two further conceptual solutions.

Candidate conceptual solutions. The three candidate conceptual solutions were:

A. The somewhat modified current lecture-centric classroom.
B. A classroom using pedagogy based on active learning.
C. A classroom environment which matches student learning styles to instructor teaching styles.[16]

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[13] It is the experience of the instructor-authors that much of the learning, where students are working in teams (syndicates), comes from interacting with other students in the team environment; essentially, the students learn from each other, and there is a social dynamic within teams. This experience matches the literature on teams in classroom environments. Empirically, different teams take on individual characters/exhibit emergent properties, indicating that they are complex subsystems in their own right. This important relationship was not considered in this case illustrating the need for domain experience as well as expertise in the systems engineering team when examining a situation.

[14] Due to the implicit assumptions discussed above, two critical operational perspective questions were not posed. These questions being "*what topics are being taught*?" and "*what topics should be taught*?" the lack of these questions focused the systems engineering on the pedagogy of the classroom and incorporated the assumption that the knowledge content met an unstated implied set of requirements. This situation provides a demonstration of how easy unstated and implied assumptions can influence the development of the system in undesirable ways unknown to the participants.

[15] Much of this research and the complete conversion of a lecture-based class on systems engineering to an active learning format was made possible by a grant from the Leverhulme Trust to Cranfield University in 2007.

[16] Is Candidate C clearly different from the others? Candidate A might be said to match student learning styles to conventional didactic teaching styles.

Consider each conceptual solution in turn.

1. The somewhat modified current lecture-centric classroom. Modifying the current approach is an obvious (intuitive?) and not necessary optimal approach which leads to a conceptual solution based on making adaptive changes. This solution is the traditional format in which the instructor is the speaker, while students are the audience. It is similar to a conference presentation session but lasts longer. It is the most familiar teaching style for students since[17] they have experienced that format in the classroom since they began their education in the first grade. Modifications could start by putting the emphasis on deep learning (Biggs, 1999) and taking into account the effect of the 'attention span' of the students. Students seem to have limited attention spans (Mills, 1953) page 32). They tend to be more attentive at the start of a lecture, as shown in Figure 4 so the effectiveness of the lecturing decreases over time[18]. This means that a break should be taken after an hour or so. If one is not taken, after an hour and half, there is a good probability that at least one person will need to answer the call of nature. If they are counting down the seconds till the break because they do not wish to disturb the class, they are not learning. (Mills, 1953) also discusses the way time should be allocated in the classroom based on providing training during World War II. Mills presented the data shown in Figure 5 (Mills, 1953) page 39). Mills' data would be useful in modifying the pedagogy of the lecture-based conceptual alternative.

2. A classroom using pedagogy based on active learning. This conceptual candidate solution is based on active learning which engages the students in the learning process rather than allow them to passively receive information from the instructor. Active learning is more than the instruction to "read, learn and inwardly digest" given out to one of the authors in Dame Alice Owens Grammar School for Boys by a teacher whose real name is long forgotten but whose nickname was "Cheyenne". Active learning has its roots in the often quoted learning pyramid developed in the 1960's at the National Training Laboratories, Bethel, Maine (Lowery, 2002), which list the effectiveness of

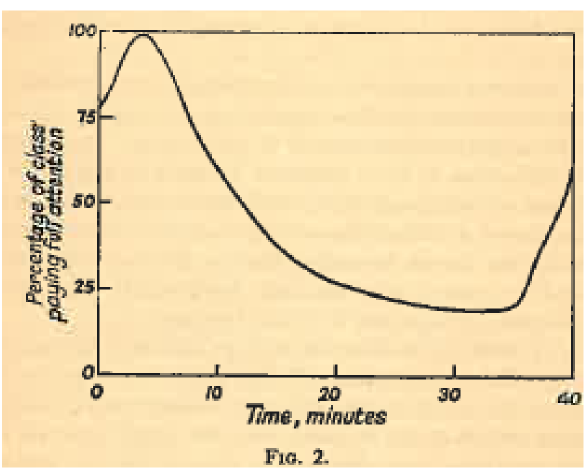

Figure 4 Attention span (Mills, 1953)

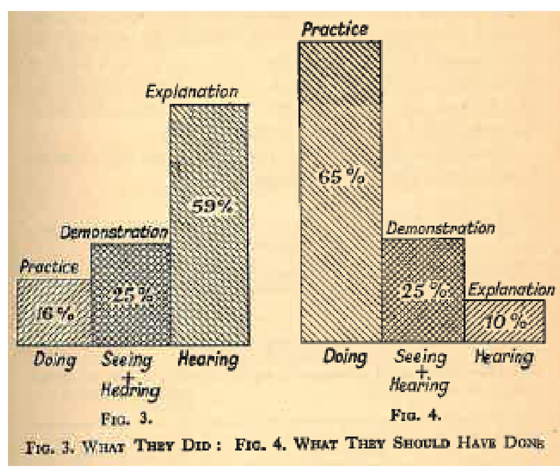

Figure 5 Classroom time (Mills, 1953)

[17] Students, note this example of critical thinking in the supporting part of the statement following the word 'since'.
[18] Conference sessions may have been originally limited to 20-40 minutes for this reason.

seven teaching methods and in the earlier Dale cone of experience[19] (Dale, 1954) page 43). The meaning of the term 'active learning' covers a broad spectrum of team work exercises ranging from 20-minute problem solving exercises to the way in which postgraduate business schools tend to work, i.e., where a lecturer introduces a subject, sets the class a problem based in the subject, and the class then spits into their teams to work on the problem[20], perhaps for a week, finally presenting their solutions in competition at the end of the week[21].

This conceptual candidate uses active learning approach set in the middle of the spectrum and is also the approach used in the world's first immersion course in systems engineering which ran twice in both Cranfield University in the UK and the National University of Singapore (NUS) in 2007 and 2008 (Kasser, 2007a). According to (Kasser, 2007a) the immersion course format produced better results in the university classroom than previous lecture-based classes did when the course was delivered in the intensive block mode format[22].

3. Match student learning styles to instructor teaching styles. According to (Felder and Silverman, 1988) "*Students learn in many ways— by seeing and hearing; reflecting and acting; reasoning logically and intuitively; memorizing and visualizing and drawing analogies and building mathematical models; steadily and in fits and starts. Teaching methods also vary. Some instructors lecture, others demonstrate or discuss; some focus on principles and others on applications; some emphasize memory and others understanding. How much a given student learns in a class is governed in part by that student's native ability and prior preparation but also by the compatibility of his or her learning style and the instructor's teaching style. Mismatches exist between common learning styles of engineering students and traditional teaching styles of engineering professors. In consequence, students become bored and inattentive in class, do poorly on tests, get discouraged about the courses, the curriculum, and themselves, and in some cases change to other curricula or drop out of school.*" This conceptual candidate looks promising. However there are many problems related to the matching between learning and teaching (Dunn and Dunn, 1979). Among others, the following questions should be answered[23].

- What are the problems in matching teaching and learning styles?
- How to design a matching teaching& learning system?
- Should the matching be done before or after students select a course?
- What should be the speed of the match, gradual or sudden?

Each of these questions must be answered. Research and various types of analysis

[19] Which does not have any numbers associated with the cone.
[20] Creating the knowledge and applying it to solve the problem
[21] In the author's experience when teaching systems engineers in a corporate environment, *competition* between teams was a valuable spur. Offering trivial prizes was a great help, as was getting the students themselves to decide after each presentation event which team was the best - and why.
[22] The class ran for four consecutive days in the first three iterations and five consecutive days in the last iteration. Students then had up to 60 days to complete the assignments. Communications with the instructor during those 60 days was encouraged.
[23] These questions are broad and may require substantial analysis to determine the pertinent parts of the findings of research performed in generating the answers to the questions.

and modelling/simulation tools may have to be employed. If the questions cannot be completely answered the elements of the solution they influence must be monitored.

Notice that at this time the descriptions of the three conceptual solutions are just sketchy concepts of operation at different levels of detail with few if any details as to how the solutions would actually function. At this point in time a milestone review takes place. Once the conceptual alternatives are accepted as being feasible, each conceptual solution would then be developed further developing an understanding of the relationships between the instructors, students and teams and how those relationships are affected by various parameters to produce a concept of operations (CONOPS) which describes in greater detail how the conceptual solution system will operate in its future environment. Models and simulations would be developed and experiments would be carried out[24]. However, should a 'show stopper' which indicates that the solution is not feasible show up at any time, work on that solution should immediately stop. Any further effort pursuing an infeasible solution is a waste of resources.

Task 3 Identify Ideal Solution Evaluation Criteria

An initial but incomplete set of solution evaluation criteria can often be extracted from personal experience and the literature during the same literature search performed to generate ideas for the conceptual solutions[25]. However in this case the literature review[26] on systems engineering education and curriculum design (e.g. (Thissen, 1997; Asbjornsen and Hamann, 2000; Brown and Scherer, 2000; Sage, 2000; van Peppen and van der Ploeg, 2000; Jain and Verma, 2007)) found that publications tended to focus on the body of knowledge for systems engineering and tended to ignore pedagogical issues, namely how systems engineering classes should be taught (Kasser, et al., 2008). (Valerdi, et al., 2009) believe that it is plausible that engineering students may prefer different learning styles depending on the content and the kind of assessment expectations which are placed upon them with respect to the abilities that they will be able to demonstrate as a result of the their study. Some evaluation criteria can be derived from student experience in a postgraduate class on systems engineering in early 2009 which employed three instructors, one after the other, teaching different topics at different levels of abstraction using different teaching styles. Student perceptions of the amount they learnt from each instructor and the differences between the instructors, the types of knowledge and the topics taught were examined and analysed to determine if the results of the analysis could provide evaluation criteria as described herein[27]. The variables/parameters

[24] These activities are really beneficial to gaining an understanding of the nature of both the problem and the solution and are a tried and tested method of developing understanding in other applied sciences - physics in particular, plus electronics, conflict management, psychology, ecology, business management, etc.

[25] This section of the paper represents the development of evaluation criteria and the presentation of information to help making the decision as to which of the alternative conceptual solutions to choose.

[26] Students – take note of the example of one way to cite a literature review performed by a third party and summarize the findings.

[27] But should students be the only source? Is it reasonable to judge relative merits of courses and instructors on the basis of student perceptions? Are students able to judge how much they have learned (and understood?), and are they able to separate their judgement from their emotions? Is this situation is akin to design departments making decisions on what they think the customer would want without actually asking

in the course included:

- Types of knowledge.
- Level of abstraction of the course content associated with the topics taught.
- Instructor teaching styles.
- Topics – each instructor provided a different part of the knowledge component[28].
- Student learning styles.

Types of knowledge. (Woolfolk, 1998) described the following three types of knowledge:

1. **Declarative knowledge.** Knowledge that can be declared in some manner. It is "knowing that" something is the case. Describing a process is declarative knowledge.
2. **Procedural knowledge.** Knowing how to do something. It must be demonstrated; performing the process demonstrates procedural knowledge.
3. **Conditional knowledge.** Knowing when and why to apply the declarative and procedural knowledge.

Prof A provided knowledge using lectures, readings and problem-based active learning. Prof A's teaching style emphasizes conditional knowledge, rather than declarative and procedural knowledge. Prof A's style affects the students in three ways. It:

1. Improves the thinking skills of the students. Prof A provides the outlines and abstracts or overviews of knowledge, and asks open-end questions expecting the students to find the answers and explanations by themselves or in groups. Prof A watches student teams at work and gently nudges them along the path of learning rather than leading the way.
2. Builds team-working spirit, the different group exercises following the introductory lecture are designed for 'learning by doing' in every class.
3. Enriches their experience in receiving the knowledge. Prof A uses multi-media (audio, video and reading materials) as additional knowledge sources for students. Examples included:

    - Using a virtual guest speaker. A 30 minute video on "systems" by Prof Derek Hitchins on systems engineering was downloaded from his web site (Hitchins, 2009) and played to the students. After the video had ended Prof Hitchins was contacted via Skype[29] and Prof A facilitated a short question-answer and discussion session.
    - Having to be at an overseas International Workshop, instead of missing an evening, the short lecture was recorded and played to the students by a colleague in the classroom. Prof A then checked in to the class using Skype[30] and by the judicious position of the camera on the laptop in the classroom by the colleague was able to view the students working on their

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the customer. Is it also similar to a group only using items they have invented or developed in-house or have direct experience?

[28] Once again the correctness of the knowledge was assumed.

[29] By prior arrangement.

[30] At 0330 his local time!

class exercise, view their presentations and make constructive comments.

- Setting a pre-class exercise in which the students were required to download Tiger Pro, an educational requirements tool containing some artificial intelligence that can tell the students if the requirements they write are bad from the testing perspective (Kasser, 2007b). The students downloaded the tool, did the exercise individually before class and submitted an individual presentation on what they had done. Prof A subsequently compiled a summary presentation containing the student-written requirements (anonymously) which showed how and why student written requirements were good and bad.
- Using the video “Pentagon Wars” (Benjamin, 1998) as a case study. The students were given a set of questions before class, watched the video in class and then answered the questions post-class in their teams. While the students did not seem to realize it, Prof A noted that lessons the students learnt from the video were indeed insightful.

Prof B provides the students with the traditional and familiar lecture using PowerPoint presentation graphics. Prof B teaches the declarative knowledge and demonstrates procedural knowledge in the daily examples within the lecture. All the key information (e.g. concepts, methodology, examples, etc) are written clearly. Prof B even enunciates ‘word by word’ the content of the slides. This traditional method has been widely accepted by the students and makes most of them feel comfortable.

Prof C teaches procedural knowledge in class. Prof C delivers knowledge using a combination of the traditional lecture followed by immediate group work. Prof C gets involved in the group work and personally interacts with the students and the groups as a consultant and facilitator. At the end of the exercises depending on the available time, the groups make presentations and share learning.

In summary, there is a difference in the type of knowledge taught by the instructors. Prof A focuses on delivering conditional knowledge, while Prof B and C focus on declarative and procedural knowledge, which make students feel more comfortable (Kasser, 2009b). Some students can’t get used to the problem based learning method in Prof A’s class because the highly abstract lecture makes them feel unclear about what they have learned. On the other hand, Prof B and Prof C deliver the typical lecture-based class with concrete information in the slides which helps the student understand the basic concepts. Moreover, Prof A and Prof C both employ some forms of active learning. Besides those methods, Prof A’s class also involves more up-front investment in teaching resources and methods, such as identifying and creating readings, videos, etc.

Topics and level of abstraction of course content. The topics and degree of abstraction of the course content was different as shown in Table 1.

Table 1 Coursework content assessment

	Coursework Topics	Level of Abstraction
Prof A	Critical thinking Problem solving Context of system engineering System design life cycle Requirements engineering	High
Prof B	Risk Management System Real Options	Low
Prof C	Business Process Reengineering (BPR) concepts Process mapping and analysis Process validation BPR practice	Medium

Teaching styles. The teaching styles and type of content was different for each instructor. The Learning Pyramid values for the degree of retention of information of the student after two weeks for each of the teaching methods (Lowery, 2002) and the approximate percentage of time allocated by the three instructors to each of the teaching methods is shown in Table 2. Two of the three instructors performed a self assessment of their teaching styles using an online Grasha-Riechmann (Grasha, 1996) pages 127 and 128) test[31] in May 2009. The results are shown in Table 3[32].

Table 2 Approximate percentage of time each instructor spent in a teaching method

Teaching Method	Learning Pyramid	Prof A	Prof B	Prof C
Lecture	5%	30%	50%	50%
Reading	10%	15%	--	--
Audio visual	20%	25%[1]	--	--
Demonstration	30%	--	50%	--
Discussion group	50%	30%[2]	--	50%[2]
Practice by doing	75%	30%[2]	--	--
Teaching others/immediate use	90%	--	--	50%[2]

Notes
1. One class session used the movie 'Pentagon Wars' (Benjamin, 1998) as the basis for a case study.
2. The activities in the two rows in the column happened simultaneously.

31 Available at http://www.longleaf.net/teachingstyle.html in May 2009.
32 Further research will have to be done to determine the significance of the differences if the information is deemed pertinent to providing the solution. This is illustrative of a situation in which analysis data is incomplete. In such instances if the solution system may be affected by the incomplete information, then the missing information become 'risks' and shall be managed appropriately. The self-assessment was done because Web site showed up on a search and the test was simple and fast. This situation illustrates that while systems engineers measure and perform analysis it is very easy for analysis-paralysis to set in. For example, questions such as "*did the test provide any useful data?*" and even "*why are we measuring this*

Table 3 Grasha-Riechmann Instructor Self-Assessment Results

	Prof A		Prof B	Prof C	
Expert	3.5	Moderate	No data	4.375	High
Formal authority	4.25	High	No data	3.625	High
Personal model	4.25	High	No data	3.627	High
Facilitator	4.25	High	No data	3.75	Moderate
Delegator	3.87	High	No data	3.5	High

Student learning styles. There were about 30 students in the class and using a tailored version of grounded theory (Glaser, 1992), eight students were interviewed about the class and their learning styles using face-to-face and telephone discussions. Each interview lasted about 30 minutes. The student responses were grouped into three types according to (Myers and Myers, 1980)'s personality research.

- Students in Type 1 are introvert thinkers. They prefer a quiet environment for learning and listening rather than talking and interacting in class. They make decisions and work directly with data, rather than with feelings, emotions and personal values. They are objective decision makers, who like to get opinions based on established facts, known procedures and linear presentations. This type of students tends to have stronger skills in memorizing details rather than in understanding abstract picture. They prefer concrete language and working directly with data. They tend to reserve judgement until all the data has been processed.
- Students in Type 2 are more likely to make decisions based on emotions, personal values or vague intuitions. They value group harmony and feel less comfortable with personal conflicts. These students tend to have stronger skills in memorizing details rather than in understanding the whole picture.
- Students in Type 3 feel more comfortable interacting with others and like talking aloud in public. They believe data and evidence, but most of the time make immediate decisions and drew premature conclusions based on initial inputs. They feel comfortable with accepting abstract knowledge and get the big picture of things first. They then look inside at the internal components, items such as the connections between seemingly random sets of data, and fill in the details later.

Student comments on the instructor's teaching styles, by Type, included:

- **Type 1:** I felt puzzled when I attend the Prof A's class. There were too many class activities that made learning experience complex. My team members and I always feel stressful and find it hard to enjoy the class. The content of Prof's B's class was also not easy, but I am quite familiar with this traditional teaching method. So it is not a problem for me to grasp the knowledge. Prof C's class made us feel easy to catch up and the number of activities is neither too much nor too little, which even inspire our interest in learning more after class.
- **Type 2:** Prof A's teaching style was quite new for most of us. We didn't have enough

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characteristic?" should be asked and answered. Analysis shall only be done if pertinent to conceptualising the solution, not because the data is available.

psychological preparation and needed time to adapt to the teaching method. Though the organization of the teaching style is simple in Prof B's class, the demonstration and lecture notes have enough detail for us to understand the knowledge. Moreover, the active individual presentation skill kind of balances the boring teaching method. Prof C's class is fun. I like the immediate practice in class, which make me feel effective learning and inspires my interest.

- **Type 3:** Prof A's lecture is at a higher level abstract for the topics, which make it hard for most of us to grasp them in the short time. But after the module, I felt I learned more and my thinking ability improved in Prof A's session, though it is still hard for me to connect it with our daily experience. We are used to Prof B's way of teaching. Though it is a little boring, I feel it doesn't depress our learning effect. What's more, his active personal presentation skills kind of balance the boring teaching method. Prof C's class makes us feel that it is easy to understand the knowledge through the immediate practice. Moreover, it makes everyone perform actively, because there are more chances to consult with Prof C personally in class during the team project.

Table 4 Summary of evaluation of alternative solutions

Conceptual Solution / **Criteria**	**Solution 1** **The somewhat modified current lecture-centric classroom.**	**Solution 2** **A classroom using pedagogy based on active learning.**	**Solution 3** **A classroom environment which matches student learning styles to instructor teaching styles.**
Teaching styles	Does not allow much variation.	Multiple styles but not matched.	Matched to student learning styles.
Types of knowledge	All	All	All
Topics	All	All	All
Degree of abstraction of the course content	Suitable	Suitable	Suitable
Student learning styles	Does not take student learning styles into account.	Variation in activities seems to allow for different learning styles at different times in the class.	Takes student learning styles into account.

In this classroom example, from the random sample[33], the majority of the students are introverts and thinking students, perhaps because of their prior engineering background. But the majority also agreed that classroom interaction and being an extrovert are also good for learning. They hoped they could be more extroverted and sociable in the light of their perceptions of the types of students in the business school. These surveyed students would like to become managers in future, managers who can perform decision making and risk management at the business level, rather than remaining as a person who can only deal with data. As the content of their degree program is positioned between engineering and business, and given their prior major engineering background, their preference for subjective and objective decision making is relatively equal.

Task 4 Trade off to Find Optimum Solution

The analysis identified variables and data that could have an effect on the solution but the results of the analysis are inconclusive[34]. When the results are summarised as shown in Table 4 the data does not appear to be useful and there is no data upon which to make an objective decision as to which of the conceptual alternative solutions to pick[35]. The evaluation criteria in this case had been determined using student provided data. But are the students a good source of evaluation criteria? There are other stakeholders – instructors, employers and the academic institution (Kasser, et al., 2008). Students can only evaluate that the way in which they were taught, they cannot evaluate that they were taught what they need to know (at least not immediately after the class ends)[36]. Other evaluation criteria need to be identified.

Looking out of the box by posing the generic perspective question *"What is this problem similar to"* one answer is a digital radio communications system where the 'ability to apply the knowledge in various situations' is the message, the instructor is the transmitter, the student is the receiver and the amount of received signal represents the learning. Maximising the received signal requires that the transmitter and receiver be on the same frequency, use the same modulation, compatible data rates and the message is transferred in an environment with minimal interference. If this analogy holds then the selected solution should be one which matches instructor teaching styles to student learning styles unless a thorough search of the education literature and the opinions of cognizant personnel in the education domain would confirm that in the last 20 years or

[33] It needs to be mentioned that the survey results may be biased and limited. This is because people tend to complain during evaluations and sometimes blame others subjectively rather than cite good points. In addition, students get used to relying on the teacher actually teaching in class, and not having to do it themselves (DIY) or self-learn. Moreover, students are reluctant to change their learning styles. Resistance to change is an important element that has to be taken into account when introducing change into any context.

[34] How much of the data is pertinent and how much is not? This is where experience is used to separate signals (pertinent data) from noise (data that is not pertinent).

[35] Had there been domain experts in the systems engineering team the results of the analysis might have been different. This result is meant to illustrate the need to have problem domain expertise and experience during the systems engineering problem solving activities.

[36] And will not pick up or question the implied assumption that the knowledge component is correct and complete.

so, research has shown that matching teaching and learning styles makes no significant difference in the effectiveness of learning systems engineering. Or should it?

The accuracy of the generic perspective analogy is critical to the success of the project; in this analogy the message is akin to the 'ability to apply the knowledge in various situations'. This analogy would drive the pedagogy towards produce Type V systems engineers (Kasser, et al., 2009) – see sidebar. Had the analogy stated the message as just being akin to the 'knowledge', the analogy would tend to drive the pedagogy towards producing Type II systems engineers which seems to be common practice (Kasser, et al., 2009) since much of systems engineering is now taught as declarative and procedural knowledge as defined by (Woolfolk, 1998). To be fair, this focus on declarative and procedural knowledge is not unique to systems engineering (Microsoft, 2008). For example, Peter Drucker wrote *"Throughout management science--in the literature as well as in the work in progress--the emphasis is on techniques rather than principles, on mechanics rather than decisions, on tools rather than on results, and, above all, on efficiency of the part rather than on performance of the whole."(Drucker, 1973)* page 509)[37].

The Five Types of Systems Engineers

- **Type I**. This type is an "apprentice who can be told "how" to implement the solution and can then implement it.
- **Type II**. This type is the most common type of systems engineer. Type II's have the ability to use the systems engineering process to figure out how to implement a physical solution once told what conceptual solution to implement.
- **Type III**. Once given a statement of the problem, this type has the necessary know-how to conceptualize the solution and to plan the implementation of the solution.
- **Type IV.** This type has the ability to examine the situation and define the problem.
- **Type V.** This type combines the abilities of the Types III and IV, namely has the ability to examine the situation, define the problem, conceptualise the solution and plan the implementation of the physical solution.

Notice that the conceptual alternative solutions have been developed without regard to cost and implementation constraints. At this stage in the systems engineering problem solving paradigm these constraints should be two of the evaluation criteria. The only time the constraints are to be considered in the development of a conceptual solution is if they become a show stopper and indicate that the solution is not feasible as discussed above.

Task 5 Select Preferred Option

The next task in the systems engineering problem solving paradigm is to select the preferred option. While the findings of the analysis are not firm, the preferred approach from the literature and the digital radio analogy is to choose an option that incorporates matching teaching to learning styles. However, the amount of work to implement the solution is unknown since the cited work was published in 1988 and systems engineering

[37] Today's academic institutions seem to be producing Type II systems engineers and managers (engineer leaders); but they should be producing or at least identifying personnel with Type V characteristics by teaching conditional knowledge.

classes are still in the main lecture-based. On the other hand, the change from the lecture-based style to the matching teaching and learning styles constitutes a paradigm shift and has experienced resistance to change. Unwillingness to unlearn something is a major cause of resistance to change. (Drucker, 1985) stated that a paradigm shift in management takes about 25 years, namely the time it takes for the 'unwilling to unlearn' proponents of the old paradigm to retire. (Kuhn, 1970) also mentions the generational delay in making a paradigm change. A simple calculation on the back of an envelope shows that 2009 – 1988 = 21. There is hope that perhaps the time to make the paradigm change is approaching. However, hoping for a solution does not guarantee success. The reasons for the resistance to the change need to be investigated, and become a prime candidate for risk determination and mitigation. Other risks to be monitored and mitigated might include those associated with matching teaching and learning styles mentioned above and issues arising from the following questions.

- Does the type of content affect the desired learning style?
- Is an individual learning style fixed or does it vary in some manner?

A fourth option? There may even be a fourth option in situations where the alternatives have been developed by different teams. Each team will generally have different degrees of expertise in different domains and produce conceptual solutions containing useful ideas. It is then likely that a fourth option could be put together based on integrating concepts from the first set of alternatives. Should this situation show up, then the process must iterate back to the start of the phase and develop the fourth conceptual solution[38]. For example, Option 1 was the somewhat modified current lecture-based classroom. It was a generic conceptual solution that would teach students in the same way. The detailed conceptual design based on further research identified eight factors for a growing and expanding teaching system (Fitzgerald, 2005). The following four factors were incorporated into the instructor's notes in the conceptual design for Option 1:

- Plan the competencies you want students to develop.
- Prepare the learning options and choices. This can be a school-wide program in which students learn about different learning styles and talent choices and how to use their strengths.
- Give students a choice of teaching styles which means provide different ways for students to receive information in the manner of Prof A. Examples would be auditory, visual, somatic and reflective experiences.
- Check and adjust. For example, if formative assessment shows that teaching technique X did not work for a student, you might try technique Y as an "adjustment".

The other four factors[39] listed by Fitzgerald were considered out of scope in this

[38] Unless the problem is in a well-understood domain, the schedule should always be planned to contain at least one iteration cycle. What would the number of iteration cycles depend on?

[39] The other four factors (Fitzgerald, 2005) that were not considered in this case study, are listed herein for further discussion:

- Begin with motivation or connection (to real life) activities. Show students how the lesson(s) will give them power and how you will help them (anchor). Give them a unique, question-generating introduction (hook) to the lesson topics.

classroom system because those factors were deemed to affect the meta-system namely the doctrine, institutional characteristics, organizational goals, resources, etc in the academic institution rather than in a single classroom[40].

Research also discovered that other factors such as teacher beliefs, teacher understanding of their roles, the syllabus time available, the textbook and the topic, preparation and the available resources, and the language proficiency of the students also need to be considered in the design of a classroom (Carless, 2003)[41]. The goal of the solution is to optimize the teaching system. This means that the pertinent factors should be incorporated into the instructor's notes in the design of the selected conceptual alternative even if they were not part of the original conceptual solution[42].

Task 6 Formulate Strategies and Plans to Implement

The next task in the process is to formulate strategies and plans for the implementation of the preferred solution. The preferred conceptual option is to match teaching and learning styles; the findings from the analysis show that the students have to be prepared for any teaching style that is not lecture-based. As such some sort of training will have to be provided. The new problem becomes how to provide both the course and the training without extending the classroom time? This is where the recursive nature of systems engineering is illustrated, because the approach to providing a solution to this new problem is the exact same six tasks shown in Figure 2 even though they all take place inside this Task as sub tasks. In this situation conceptual solutions might include:

- Providing training to instructors teaching in the programme.
- Providing training to the students at the start of every class in the degree programme.
- Providing training to the students at the start of the degree programme.
- Don't provide training to the students but identify individual student learning styles and stream the students in classes taught by different instructors using different teaching styles (either for the entire degree programme or individual classes) which match the learning styles of the students.

- Provide different tasks so that students can use talent or intelligence preferences and develop other talent strengths to demonstrate learning. Here you have tasks that let them "construct meaning," the true measure of learning. This is the area of multiple intelligences.
- Promote mastery with some different re-teaching where necessary. Some of this might come after formative assessment The goal is student competence, i.e. not "20% missed is good enough!"
- Celebrate success. Document competencies achieved or not achieved so that the next teacher can follow-up properly. Remember that congratulations help students take pride in learning.

[40] Factors that affect the meta-system need to be addressed in the context of the meta-system configuration control and not just noted in the single system and ignored/forgotten!

[41] However, this research was performed in a primary school in Hong Kong and the relevance of factors affecting primary school teaching in that culture to those factors affecting postgraduate systems engineering teaching in this culture needs to be determined and if, and only if, applicable, incorporated into the preferred conceptual solution. This anecdote illustrates a serious issue. Lessons learned from one context shall not be incorporated into another context without a full understanding of the context from which those lessons were learnt and how much of that context is applicable on the current project.

[42] Similarly in any project, serious consideration should be given to incorporating factors contributing to the success of one conceptual alternative solution into the preferred solution if those factors are solution independent.

The feasibility of each of these alternatives would have to be determined, evaluation criteria established, a solution chosen and the appropriate CONOPS and implementation plans developed. Given that there is a high degree of uncertainty the solution classroom system should be implemented in phases using an evolutionary approach such as (Kasser, 2002). The plans for the implementation of the solution system may be documented in the Systems Engineering Management Plan (SEMP).

Iteration required

Hold everything! New information has come to light[43]. Further research found a report addressing the issue of the relationship between instructor's learning style, student style and the impact that the degree of instructor commitment to a particular mode may have on student achievement in students enrolled in freshman English (Davis, et al., 1988). The method used to assess student learning styles was based on (Kolb, 1984). The results in the report stated that there was no significant difference in course grade point averages among students who were matched or partially matched with, or held opposite styles to, their instructors. The Davis report provided several reasons for the inconclusive results and recommended further research. These findings need further research. However, if the findings are valid then a new alternative may become feasible.

As mentioned above, the majority of students in the sample are introverts. This situation is supported by the newly discovered statement by (McClure, 2004) who when reviewing (Laney, 2002) began the review with "*Are you an introvert? Only a quarter of the general population is, but more than half of engineers are*". Another set of conceptual alternative solutions for classes teaching systems engineering could be based on (1) verifying a hypothesis that systems engineers, as a subset of engineers, tend to be introverts and then (2) creating a classroom teaching and learning system based on the learning styles of introverts as the norm rather than on matching teaching and learning styles. The literature on learning styles contains a number of different ways of expressing and evaluating learning styles including:

- The VARK (Visual, Aural/Auditory, Read/Write, and Kinesthetic) learning style

Table 5 ILS Learning and teaching styles

Learning Style	**Teaching Style**
Sensory, intuitive-perception	Concrete, abstract-content
Visual, auditory-input	Visual, verbal-presentation
Inductive, deductive-organization	Inductive, deductive-organization
Active, reflective-processing	Active, passive-student participation
Sequential, global- understanding	Sequential, global-perspective

[43] This paragraph demonstrates that changes in the state of the art as well as the customer can provide new information or describe a new need anytime in the development of the solution system and sometimes that new information means that the work already done is no longer valid and the process has to start again, from the beginning of the appropriate earlier stage. In practice this restart delays the completion of the project by the amount of time taken to get back to the point at which the iteration began (schedule delay)

instrument which divides learning styles in response to the input forms of 'visual', 'aural/auditory', 'read/write' and 'kinesthetic' forms (Fleming and Mills, 1992).

- The Grasha-Reichmann model developed in the early 1970s and used for more than two decades to identify the preferences learners have for interacting with peers and the instructors in classroom settings (Grasha, 1996) pages 127 and 128).
- The Index of Learning Styles (ILS), (Felder and Soloman, 2008), a model which classifies instructional methods according to how well they match the teaching and learning styles shown in Table 5.

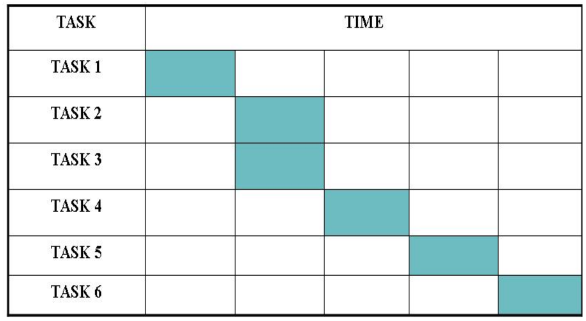

Figure 6 Representation of Figure 1 in Gantt chart Format

The documents would be reviewed and data extracted and correlated to the needs of introverts and a new set of conceptual alternative solutions conceived. These conceptual solutions could even provide a lower cost more effective solution than those already identified and minimise or even eliminate the need for training students and

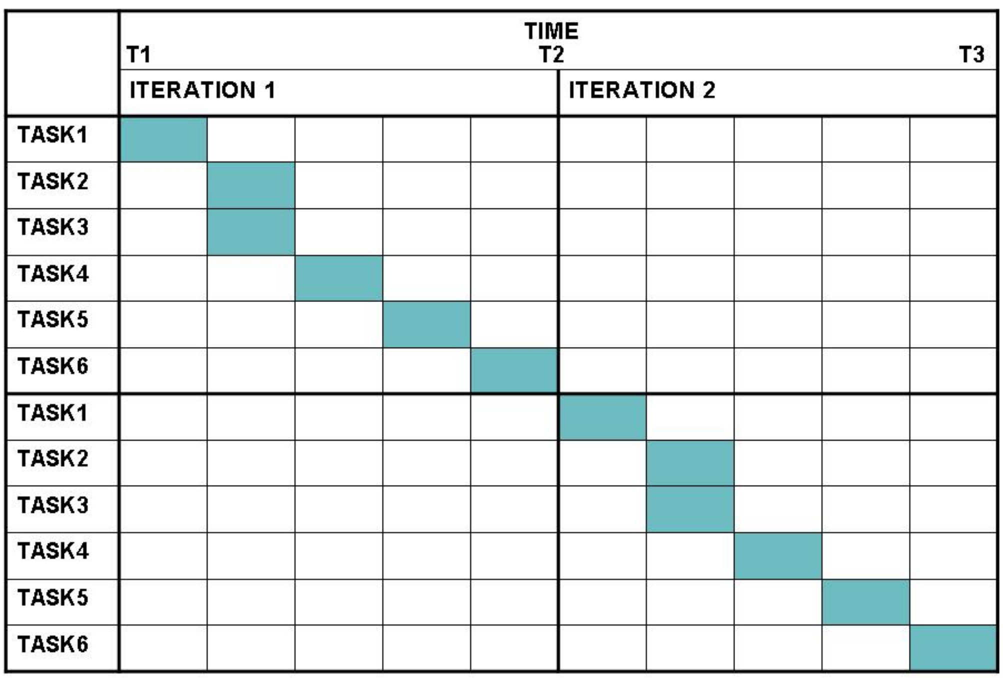

Figure 7 Gantt chart representation of schedule delay due to Iteration of full sequence of tasks

and incurs costs due to the resources expended in the unplanned iteration (cost escalations). Good project planning should allow for a number of iterations.

instructors, both of whom are engineers.

This new information changes the rules[44] and means that the problem solving activity returns to the start of the Task 2 and Task 3 boxes in Figure 2. Iteration from the end of a sequence of tasks back to the start is generally added in drawings such as Figure 2 by adding a feedback arrow from the output to the input. The drawing is a representation of the iteration. However, it does not take the time factor into account. If Figure 2 is redrawn in Gantt chart[45] form as shown in Figure 6 where the six tasks have been relabelled as Tasks 1 to 6 for simplicity[46], the effect on schedule and cost of the iteration may be readily seen when the second set of tasks are added into the Gantt chart as shown in Figure 7[47]. The original time from start to finish was T1 to T2; the changed time is T1 to T3 and the additional time is T2 to T3. In this instance, this Gantt chart view indicates that iteration takes place from the end of a sequence of tasks back to their start which is not always the case. Iteration may start anywhere in the sequence of tasks if deemed appropriate and may iterate back to any previous task. Knowing how and when to iterate or repeat tasks[48] is an important competency in architecting the systems engineering problem solving process for a project (Kasser, 2005).

Yet another iteration? The introduction to the paper mentioned that there was an unstated and implied constraint or assumption that the solution system was limited to the classroom environment and online distance mode options were out of scope. If the customer changes her mind and distance mode options become allowable or even desirable, the process must iterate another time, to examine conceptual distance mode alternatives and compare them with the already developed solutions, with corresponding cost and schedule escalations.

Afterword

This section provides some comments on the following two issues.

- The choice of process.
- Challenging assumptions

The choice of process. In this case, the customer stated the problem as the need to provide postgraduate students studying systems engineering in a classroom[49]. It might

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[44] When doing research (for a dissertation or grant) the literature review has to be ongoing (a background task) since new findings may change or even invalidate the research in process.

[45] Flow charts and Gantt charts are two different views of underlying project information and should be used appropriately depending on what information is being considered, analysed or communicated.

[46] This need to keep the information in drawings simple is one of the reasons for providing Work Breakdown Structure (WBS) task elements and requirements with respective identification numbers.

[47] In common parlance, iteration need not be for the whole cycle to be repeated; instead, only some parts may be repeated. So Figure 7 may be overstating the case!

[48] As well as when to stop work on a task; the sixth role of a systems engineer (Jenkins, 1969 page 164)

[49] The problem explored so far in this paper was the customer provided problem. However, it may not have been the real problem, for a number of reasons including:

- The point of education and training in systems engineering is not to please the students, although if they are enjoying the process, they will learn more effectively. Nor is it to get them to pass exams. As mentioned in a footnote, surely, the value of a systems engineering can be judged only by outcome - by the quality of the students, perhaps 3 to 4 years down the road, when they have jobs in the business and have been advantageous if, instead of the standard systems engineering problem-solving paradigm shown in Figure 2 an alternative shown in Figure 8 had been chosen (Hitchins, 2007) page 174). This alternative process addresses the problem in more detail, which seems very important in this case and should have driven down to the root of the issue: which has teased and frustrated educators for decades! Having said that, the systems engineering problem-solving paradigm provided a rational basis around which to conceptualise the solutions to the problem as stated by the customer[50].

Challenging assumptions. The eighth of (Jenkins, 1969) page 164) twelve roles of a systems engineer was "*He challenges the assumptions on which the optimization is based*." None of the systems engineers on this project did so, specifically with regard to challenging the solution stated by the customer. However, sometimes challenging the solution stated by the customer can lead to undesired emergence. For example, in the mid 1980's a data processing facility at the National Aeronautical and Atmospheric Administration's (NASA) Goddard Space Flight Center was in the middle of a facility upgrade project. The facility processed data downlinked from low earth orbiting spacecraft and was running out of capacity. Working on the project were NASA, contractor and subcontractor personnel. At an early meeting the NASA project manager drew an optical Fiber Distributed Data Interface (FDDI) ring architecture on the white board and issued

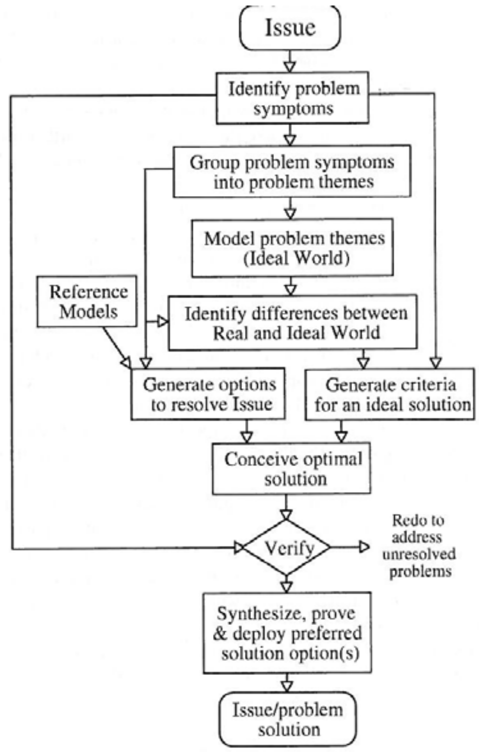

Figure 8 Combined general and systems engineering problem-solving paradigms (Hitchins, 2007)

they can look back and reasonably determine what the course gave them that has proved useful. So, outcome is more valuable than output.

- The content aspect was not addressed in this case other than mentioning the topics taught by each of the instructors in Table 1. There was an implicit assumption that the content was correct. However, (Kasser et al., 2008) stated that research showed that courses in systems engineering were generally not teaching the things systems engineers needed to know, they were teaching the things the faculty could teach! Now, with systems engineering students, surely we are trying to promote understanding, as much as instilling knowledge. An understanding of systems, systems thinking and systems engineering is founded on systems science and systems theory: without these, there would be no anchor. So, it seems that any systems engineering course that is going to be successful in promoting understanding of systems engineering is going to have an up-front element of systems thinking, systems science (wholes, open systems, systems approach, emergence, etc.) such that the student can see the point of it all. (And case studies of a few disasters might not go amiss).

[50] The choice of appropriate process and the tailoring of the process to fit the situation is an important aspect of the role of the systems engineer. The process and the degree of formality in the documents shall be appropriate to the project.

a fiat that he had just drawn the system architecture. "FDDI has a 100 Megabit data rate, it's a neat technology to use, so we are going to use it" he said as he completed the sketch and sat down. The members of the contractor's organisation said nothing. The subcontractor's lead systems engineer politely suggested that perhaps they needed to do an analysis of the data rates[51]. The NASA project manager firmly restated that the decision had been made and the matter was closed[52]. Two weeks later the subcontractor's lead systems engineer was removed from the project at the request of the NASA project manager. The stated reason was that the subcontractor's lead systems engineer was 'too arrogant'. In this situation the assumptions were questioned without conscious thought of the decision to perform the questioning. However, conscious recognition of the need to question the assumptions can sometimes lead to an ethical dilemma as described in (Kasser, 1995b) and Chapter 19 in (Kasser, 1995a) pages 237 to 251). Things went well during the facility upgrade design phase and at no time during this process did any of the contractor or subcontractor personnel disagree with the NASA project manager[53]. Several months later, when data flow problems became apparent, another non-systems engineering rethink by the NASA personnel determined that the system would use two FDDI rings in series; one for input data and one for output data[54].

This anecdote has been an example of how, in some situations, the customer inserts a fundamental flaw into the solution system at the start of the process and systems engineering gets the blame when the solution system does not meet the need, or the implementation suffers from technical problems and cost and schedule escalations resulting from that flawed solution.

Summary

This paper has provided a teaching case study to illustrate the conceptual early stages in systems engineering using the example of tackling the problem of providing postgraduate students with an optimal learning environment as an example of factors to be considered in the conceptual early stages of systems engineering, how the seeds of doom can be planted into a project in the early stage and how recursion and iteration are invoked in the systems engineering process. Questions and comments were provided in the text, in footnotes and in the afterword to facilitate discussion in class.

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[51] He felt that the concept of using fiber optic connections was valid, but there were viable alternatives to a ring structure (such as a matrix or cross point switch approach), especially as they would be dealing with:

- Receiving and processing real--time data.
- A number of spacecraft providing the data.
- Incoming data rates of up to 10 Megabits.
- Several input data processing elements (workstations).
- Several output data processing elements (workstations).
- Output data rates of between 5 and 10 Megabits.
- Data transfers between the input and output processing elements.

[52] He had read about it in a magazine and so was the subject matter expert!

[53] Either they didn't want to upset him and get transferred, or they knew that NASA would later pay them to fix the problems – it was a Cost Plus contract.

[54] Notice they were still locked into a ring architecture solution.

Conclusion

The systems engineering in this case was sound in that the process was done by the book. However, the seeds of doom have been planted[55] since the customer initially stated the problem as the need to provide postgraduate students studying systems engineering in a classroom with the necessary knowledge and skills components in an optimal manner. Accepting that statement, the systems engineering addressed the pedagogy limited to the classroom environment. The systems engineering also ignored the knowledge and skills components due to the implied assumption that the knowledge and skills component in the class were adequate. As a consequence, the project has a high probability of failure[56]. That is, the subsequent processes for engineering the solution system will deliver the wrong solution system irrespective of which systems engineering Standard the process follows and the development organisation's level of Capability Maturity!

There are lessons to be learned from this case that apply to a broad range of projects in both civilian and Defence domains. Lessons learned[57] include:

- Identification of the correct problem is critical. If the wrong problem is identified, the wrong solution system will be produced.
- Implicit and unstated assumptions potentially comprise seeds of doom.
- Solution systems can be adaptations of exiting systems or new and innovative systems.
- Good systems engineering in the early stages of a project is vital.
- The choice of process to tackle the problem and implement the solution is as important as the choice of solution system.
- Following a perfect process can still produce a poor product. This is commonly known as garbage-in-garbage-out (GIGO).
- Analysis should stop once the solution is deemed to be infeasible.
- Experience, excellence and knowledge in both systems engineering and the domain are needed in a project.
- Iteration needs to be built into a project schedule, the higher the level of uncertainty, the greater will be the number of iterations required. Building iteration into the schedule reduces cost and schedule overruns due to unplanned iteration.
- Use appropriate views of project data to minimise misunderstandings. Gantt charts for schedules (temporal views), functional flow charts for functional views, etc. a single view does not fit all purposes.
- Challenging assumptions can be an ethical challenge in itself.
- Using system thinking to view the problem *as a whole* from different perspectives is necessary through the whole problem solving process.
- Students shall not be the sole evaluators of good teaching. This can be generalised to state that users of a system shall not be the sole evaluators of conceptual replacement

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[55] And pointed out in the text or in footnotes.

[56] Would this be a valid reason to start the Independent Verification and Validation (IV&V) activities at the same time as the solution providing activities?

[57] In the classroom, students could be asked to make a short presentation on each of these lessons learned and how the lesson applies in this instance and in other situations.

systems[58].

Biographies

ZHAO Yang Yang is currently completing a Master's in System Design and Management at National University of Singapore. After her receiving first Master's degree in Engineering Management from City University of Hong Kong, she worked as a Research Assistant at the Department of Manufacturing Engineering and Engineering Management, City University of Hong Kong before moving to Singapore. She is interested in system engineering, management of technological innovation and entrepreneurship strategy, etc.

Joseph KASSER has been a practicing systems engineer for nearly 40 years and an academic for about 10 years. He is an INCOSE Fellow, the author of "A Framework for Understanding Systems Engineering" and "Applying Total Quality Management to Systems Engineering" and many INCOSE symposia papers. He is a recipient of NASA's Manned Space Flight Awareness Award (Silver Snoopy) for quality and technical excellence for performing and directing systems engineering and other awards. He holds a Doctor of Science in Engineering Management from The George Washington University, is a Certified Manager and holds a Certified Membership of the Association for Learning Technology. He has also served as the initial president of INCOSE Australia and Region VI Representative to the INCOSE Member Board. He gave up his positions as a Deputy Director and DSTO Associate Research Professor at the Systems Engineering and Evaluation Centre at the University of South Australia in early 2007 to move to the UK to develop the world's first immersion course in systems engineering as a Leverhulme Visiting Professor at Cranfield University. He is currently a principal at the Right Requirement Ltd. in the UK and a Visiting Associate Professor at the National University of Singapore.

Derek HITCHINS retired from full time academic work in 1994 on medical grounds, and is now a part-time consultant, teacher, visiting professor and international lecturer. Formerly, he held the British Aerospace Chairs in Systems Science and in Command and Control, Cranfield University at RMCS Shrivenham. Prior to that, he held the Chair in Engineering Management at City University, London. Derek started as a Cranwell apprentice and retired as a wing commander from the Royal Air Force after 22 years, to join industry. His first industry appointments were as the System Design Manager of the Tornado F3 Avionics, Technical Co-ordinator for UKAIR CCIS, and UK Technical Director for the NATO Air Command and Control System (ACCS) project in Brussels. He subsequently held posts in two leading systems engineering companies as Marketing Director, Business Development Director and Technical Director before becoming an academic in 1988. His current research is into system thinking, system requirements, social psychology & anthropology, Egyptology, command & control, system design and world-class systems engineering. He has published three systems engineering books: "Putting Systems to Work", John Wiley & Sons, in 1992; "Advanced Systems Thinking, Engineering and Management," Artech House, 2003; and, "Systems Engineering: A 21st

[58] Because their focus is too narrow.

Century Systems Methodology," John Wiley & Sons in 2007/2008. He inaugurated the IEE's PG M5 — Systems Engineering. He also started the UK Chapter of INCOSE and was its inaugural president. He is an INCOSE Fellow, an INCOSE "Pioneer" and a Charter Member of the Omega Alpha Association.

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