Introducing the balanced classroom:

Applying systems engineering to systems engineering education

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Abstract. According to the literature, previous research on systems engineering education and curriculum design focused on the nature of the knowledge to be taught, and tended to ignore pedagogical issues. This paper:

- Presents some of the results of research and development into both the knowledge requirements for, and pedagogy of, teaching and learning in postgraduate classes in systems engineering, project management and innovation management, lasting from 1998 to 2015.
- Focuses only on the pedagogy.
- Suggests that instead of adopting a single technique such as the "flipped classroom" an Authentic Learning Environment or games/simulations, a number of teaching techniques (subsystems) should be used together in an interdependent manner blending them to enhance the learning experience in the classroom (the system).
- Describes a balanced classroom, a system which mixes a number of previously tested teaching and learning subsystems in a synergistic manner.
- Concludes with a brief summary of the results of using the balanced classroom in three different classes at the National University of Singapore (NUS) in 2013 and 2014.

The contributions of the balanced classroom to teaching and learning are:

1. It is the first time that all the subsystems have been used (integrated) together interdependently as a system.
2. It overcomes the major defects in the 'flipped classroom'.

Keywords: systems engineering education, systems integration, balanced classroom, problem-based learning, flipped classroom, activity based learning, authentic assessments, an Authentic Learning Environment.

1 Introduction

"*The purpose of systems engineering education is to shorten the time needed to become a systems engineer. In the past, engineers became systems engineers*[1] *after 10-25 years of practical experience. The challenge is to shorten this to 5-10 years*" (Enger, 2012). This paper:

1. Discusses a part of applying systems engineering to the problem of optimising post-

[1] Lead or Chief systems engineers who can supervise and mentor junior systems engineers working on complex projects.

graduate education pedagogy to meet Enger's challenge for part-time mature students.
2. Focuses on pedagogy not the knowledge being taught.

Accordingly, Section 2 summarizes some of the requirements for the balanced classroom developed during the research. Section 3 summarises the research and development leading up to the balanced classroom. Section 4 describes the architecture of, and subsystems in, the balanced classroom. Section 5 outlines how the balanced classroom is used covering the three parts of each session. Section 6 shows how the three types of content free knowledge are incorporated into the balanced classroom. Section 7 shares some of the results using the balanced classroom in three different classes at NUS in 2013 and 2014. Section 8 summarises the paper. Section 9 contains some conclusions. Section 10 contains some ideas for further follow on research. The contributions of the balanced classroom to teaching and learning are:

1. It is the first time that all the subsystems have been used (integrated) together interdependently as a system.
2. It overcomes the major defects in the 'flipped classroom'.

The starting point for the research was the typical experience-based class. After much reflection of the author's classes and others he audited as a program director and interested participant, in general the knowledge content of a class was based on a combination of:

1. A textbook based on the author's knowledge and experience, in most cases written from a single perspective.
2. The instructor's experience as a practitioner[2] which augmented the text book.
3. Occasional readings from conference papers and other textbooks.

The content was generally stand-alone in that it lacked the anchor points to existing knowledge in other classes in the degree program and did not place the knowledge in context. As a result, the author's impression was that the learning experience was less than it could be, namely:

- Students who understood the topic at the start of the class, understood it better at the end of the class.
- Students who didn't understand the topic at the start of the class, didn't understand it less at the end of the class.

And it was this undesirable situation that prompted the research into increasing the effectiveness of postgraduate teaching and learning in systems engineering.

2 Requirements for the balanced classroom

Earlier research developed requirements for the pedagogy of the class (Kasser, 2007a). This section summarizes the updated requirements and the reasons for the requirements, namely:

1. The pedagogy of the class shall provide industry and government with a pool of skilled personnel for the acquisition and maintenance of the systems that underpin 21st century civilization as discussed in Section 2.1.
2. The pedagogy of the class shall provide students with the opportunity to exercise the five top aspects of the engineering design process that best equip secondary students to understand, manage, and solve technological problems (Wicklein, et al., 2009) as discussed in Section 2.2.
3. The pedagogy of the class shall use the most effective teaching and learning approach as discussed in Section 2.3.

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[2] For those classes where the instructor had work experience.

4. The pedagogy of the class shall produce Type V systems engineers (Kasser, et al., 2009) and project managers as discussed in Section 2.4.
5. The pedagogy of the class shall assess the cognitive skills of the students including the degree of critical thinking as discussed in Section 2.5.
6. The pedagogy of the class shall maximise student attention span as discussed in Section 2.6.
7. The pedagogy of the class shall teach the three types of propositional knowledge discussed in Section 2.7.
8. The pedagogy of the class shall provide the students with the opportunity to exercise the higher level skills and competencies discussed in Section 2.8.
9. The pedagogy of the class shall include real world scenarios to provide an experience component as discussed in Section 2.9.

2.1 A pool of skilled personnel

Industry and government require a pool of skilled personnel for the acquisition and maintenance of the systems that underpin 21st century civilization (Kasser, 2007b). These personnel:

- Are competent, skilled and knowledgeable systems engineers and project managers capable of effectively working on various types of complex multi-disciplinary integrated systems in different application domains, in different portions of the system lifecycle, in teams, alone, and with cognizant personnel in application and tool domains.
- Have a firm foundation based on three legs:
  - ***Systems engineering:*** knowledge of systems engineering processes, experience in systems engineering processes.
  - ***Ability to identify and solve correct problems:*** systems thinking, critical thinking and problem-solving.
  - ***Interpersonal skills:*** including communications and personal relationships.
- Need to understand the principles of systems engineering and be able to explain the principles to their juniors.

2.2 The five top aspects of the engineering design process

The five top aspects of the engineering design process that best equip secondary students to understand, manage, and solve technological problems (Wicklein, et al., 2009) were:

1. Understanding that there may be multiple solutions to a problem/requirement.
2. Effective oral communications.
3. Ability to communicate graphically and pictorially.
4. Ability to handle open-ended/ill-defined problems.
5. Ability to perform systems thinking.

2.3 The claimed effectiveness of learning approaches

According to the often quoted Learning Pyramid developed in the 1960s at the National Training Laboratories, Bethel, Maine (Lowery, 2002), and the earlier Dale Cone of Experience[3] (Dale, 1954), which have been combined and redrawn as Figure 1 (Kasser, et al., 2008), listening to lectures is the worst way of learning

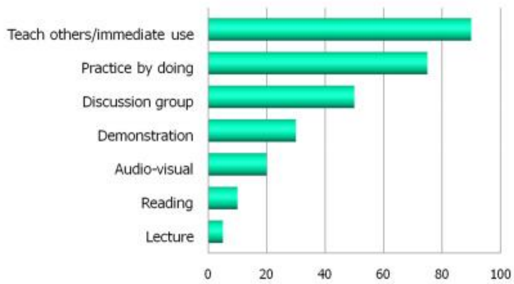

Figure 1. Claimed effectiveness of different learning techniques (Kasser, et al., 2008)

[3] There are no numbers associated with Dale's cone.

while any of the forms of active learning is better.

2.4 Produce Type V systems engineers and project managers

Perceptions of systems engineering from the *Quantitative* perspective identified the following five types of systems engineers based on observations of their ability to deal with problems and solutions (Kasser, et al., 2009).

- ***Type I:*** apprentices who have to be told "how" to implement the solution system.
- ***Type II:*** imitators/doers. This type is the most common type of systems engineer. Type IIs have the ability to follow a process to implement a physical solution system once told what to do.
- ***Type III:*** problem solvers. Once given a statement of the problem, this type has the expertise to conceptualize the solution system and to plan the implementation of the solution, namely create the process to realize the solution.
- ***Type IV:*** problem formulators. This type has the ability to examine the situation and define the problem (Wymore, 1993) page 2), but cannot conceptualise a solution.
- ***Type V:*** engineer-leaders, pathfinders or innovators. This type is rare and combines the abilities of the Types III and IV, namely has the ability to examine the situation, define the problem, conceptualise the solution system and plan and manage the implementation of the physical solution.

2.5 Assessment of cognitive skills

The cognitive skills of students may be assessed using:

1. The updated Bloom's taxonomy (Overbaugh and Schultz, 2013) shown in a pyramid format in Figure 2.
2. Existing ways of measuring critical thinking. A literature review showed that the problem of assessing the degree of critical thinking in students seemed to have already been solved by several different people in several different ways, e.g. (Facione, et al., 2000; Eichhorn, 2002; Wolcott and Gray, 2003; Allen, 2004; Paul and Elder, 2006; Perry, 1981; Gordon G. et al., 1974; Gharajedaghi, 1999). Wolcott and Gray's method for assessing a critical thinking level was very similar to that used by (Biggs, 1999) for assessing deep learning. Since a modified version of the Biggs criteria had been used successfully at the University of South Australia (UniSA) (Kasser, et al., 2005) for assessing student's work, Wolcott's method was selected (Kasser, 2013).

Figure 2. Updated Bloom's taxonomy (Overbaugh and Schultz, 2013)

Gordon et al. provided a way to identify the difference in cognitive skills between innovators, problem formulators, problem solvers and imitators (Gordon G. et al., 1974). The difference shown in Figure 3 which is based on a table in Gordon et al. (Gordon G. et al., 1974) as cited by (Gharajedaghi, 1999) is based on:

- Ability to find ***differences*** among objects which seem to be ***similar.***
- Ability to find ***similarities*** among objects which seem to be ***different.***

The differences in the '***ability to find*** …' leads to the different types of personalities. For example,

- ***Problem formulators*** score high in ability to find differences among objects which seem to be similar.

- ***Problem solvers score*** high in ability to find similarities among objects which seem to be different.

From a slightly different perspective, Gharajedaghi discussed four personality types based on the same abilities in the context of separating the problem from the solution (Gharajedaghi, 1999) pages 116-117) where:

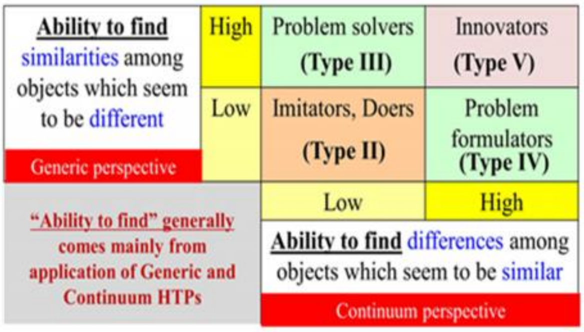

Figure 3 Matching cognitive skills to the five types of systems engineers

- ***Leaders and pathfinders*** (innovators in Figure 3) have a holistic orientation to ***seeing*** the bigger picture and putting issues in the proper perspective.
- ***Problem solvers*** are ***scientifically*** oriented with a tendency to find similarities in things that are different. They are concerned with immediate results.
- ***Problem formulators*** are artistically oriented having a tendency to find differences in things that are similar. They are concerned with the consequences.
- ***Doers*** are practitioners producing tangible results following established processes.

Four of the five types discussed in Section 2.4 were then matched to the factors conducive to innovation as shown in Figure 3. Type IIs tend to:

- Rate low in their ability to identify similarities among objects that appear to be different as well as their ability to identify differences among objects which seem to be similar.
- Look for patterns and follow the process for dealing with the pattern.

2.6 Student attention span

Studies in the UK in the late 1940s and 1950 in classes teaching technical topics associated with repairing communications equipment produced the graph shown in Figure 4 (Mills, 1953). According to in Figure 4 student attention span needs to be reset at least every ten minutes, preferably sooner.

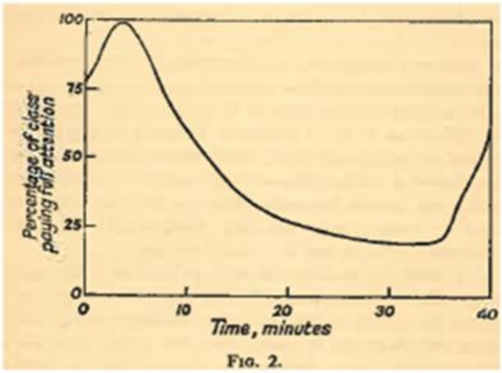

Figure 4 Attention span (Mills, 1953)

2.7 Three types of propositional knowledge

While knowledge may be classified in many ways, the following three types of propositional knowledge (Woolfolk, 1998; Schunk, 1996) page 166) provide a useful content-free classification useable in all pedagogies and domains:

1. ***Declarative knowledge:*** knowledge that can be declared in some manner, e.g. facts, subjective beliefs and organised passages. It is "knowing that" something is the case. For example, describing a process is declarative knowledge.
2. ***Procedural knowledge:*** knowing how to do something. It consists of rules and algorithms and must be demonstrated. For example, performing a process demonstrates procedural knowledge.
3. ***Conditional knowledge:*** knowing when and why to tailor and apply the declarative and procedural knowledge and why it is beneficial to do so.

Research findings showed that there is a general tendency to focus on teaching Declarative and Procedural knowledge and minimise teaching Conditional knowledge. However, in order to meet the requirements in Section 2.1 the pedagogy needs to provide the students with the opportunity to use Conditional knowledge, namely exercise the higher levels in the updated Blooms taxonomy.

The general tendency to focus on teaching Declarative and Procedural knowledge and minimise teaching Conditional knowledge may be because:

1. Many students with little work experience in higher positions in the organisation do not realise that they need Conditional knowledge in the real world.
2. When exercising Conditional knowledge there is generally more than one acceptable solution and many students are uncomfortable with not having a single correct solution or model answer.
3. Uncomfortable students tend to give their instructors poor evaluations at the end of the semester. Hence instructors who want good student evaluations to meet tenure requirements tend to focus on problems with a single correct solution or model answer.
4. Applying Conditional knowledge means that the students need to understand the knowledge which takes more work than memorization. Consequently, the class is a harder class than one that just requires memorization.
5. Based on observations of a number of classes at University of Maryland University College (UMUC)[4], students end to give higher evaluations to easy classes than to harder classes. Hence instructors who want good student evaluations to meet tenure requirements tend to make the classes easy and focus on Declarative and Procedural knowledge.

After experiencing the balanced classroom pedagogy, particularly the Authentic Learning Environment discussed in Section 2.9, students tend to realise that they need the Conditional knowledge in the real world and that reflects in the good student evaluations of the balanced classroom pedagogy discussed in Section 7.

2.8 Skills and competencies

The literature also contains a number of suggestions for what should be incorporated into the classroom experience[5]. For example:

- Brown and Scherer suggest incorporating the following features into the classroom experience (Brown and Scherer, 2000):

  1) Use of open-ended problems.
  2) Encouragement/development of student creativity.
  3) Use of the systems design methodology.
  4) Consideration of alternative solutions.
  5) Detailed system design specifications.
  6) Use of decision methodologies.
  7) Consideration of feasibility, reliability, and maintainability.
  8) Inclusion of economic, social, ethical, aesthetic, and economic impacts.
  9) Use of real problems with real clients.

- The American Society for Engineering Education (ASEA) provided the following list of ingredients associated with reshaping the curriculum (Sage, 2000) citing (ASEA, 1994).

  1) Team skills, collaborative and active learning.
  2) Communication skills.
  3) A systems perspective.

[4] The author's and those of other instructors observed as part of the author's duties a Program Director.

[5] However, the literature rarely shows how to incorporate the suggestions.

4) An understanding and appreciation of diversity.
5) Appreciation of different cultures and business practices, and understanding that engineering practice is now global.
6) Integration of knowledge throughout the curriculum a multidisciplinary perspective.
7) Commitment to quality, timeliness, continuous improvement.
8) Undergraduate research and engineering work experience.
9) Understanding of social, economic, and environmental impact of engineering decisions.
10) Ethics.

2.9 Real world scenarios

One way to meet Enger's challenge seems to be to add the opportunity to gain experience by including real world scenarios in a class in the form of an Authentic Learning Environment which has the following ten design characteristics (Reeves, et al., 2002) cited by (Herrington, et al., 2004):

1. Authentic activities have real-world relevance.
2. Authentic activities are ill-defined, requiring students to define the tasks and subtasks needed to complete the activity.
3. Authentic activities comprise complex tasks to be investigated by students over a sustained period of time.
4. Authentic activities provide the opportunity for students to examine the task from different perspectives, using a variety of resources.
5. Authentic activities provide the opportunity to collaborate.
6. Authentic activities provide the opportunity to reflect.
7. Authentic activities can be integrated and applied across different subject areas and lead beyond domain-specific outcomes.
8. Authentic activities are seamlessly integrated with assessment.
9. Authentic activities create polished products valuable in their own right rather than as preparation for something else.
10. Authentic activities allow competing solutions and diversity of outcome.

The requirements for the Authentic Learning Environment contain many of the requirements listed in the previous sections particularly those in Sections 2.2 and 2.8 however, space limitation precludes the discussion of traceability.

3 Summary of the research and development leading up to the balanced classroom

Space limitations preclude a detailed description of the iterative Systems Development Process (SDP) that produced the balanced classroom as a system that meets the requirements in Section 2. The SDP took place over about twelve years transitioning from the initial lecture-centric classroom in both traditional face-to-face and online classrooms in a number of iterations. There was also one challenging class which contained one traditional face-to-face synchronous section at UMUC in Maryland combined with one asynchronous online section with an instructor in Adelaide, Australia (Kasser, 2001).

Except for one iteration of one class, the number of students in a class ranged from seven to 35. Although pre-recorded lectures had been used in online classes since 1998, the first time the pre-recorded lecture was used in a face-to-face class was in the first iteration of

SDM5004 at NUS in 2011 where the student attendance was 70[6]. The pre-recorded lecture in the face to face class was a solution to the problem of how to allow all student teams to make a presentation in the limited classroom time[7].

The major elements of the research and development included:

1. The development of the knowledge reading concept discussed in Section 3.1.
2. The difference between synchronous and asynchronous lectures discussed in Section 3.2.
3. The different technology for recording the lectures discussed in Section 3.3.

Consider each of them.

3.1 The development of the knowledge reading concept

After noting that some students were not reading the required material before the session, research into how to ensure the students did read the material commenced. The initial attempt to encourage the students to read the material in 1998 was to require the students to lecture one chapter from the textbook. It worked reasonably well. A different approach was tried in 2010 by making the title of the reading arouse student curiosity (Kasser, 2011). It worked but was limited to a single reading. The knowledge readings (Kasser, 2013) discussed in Section 4.3 overcame that limitation.

3.2 A difference between synchronous and asynchronous lectures

The early recordings were for the online classes at UMUC. A difference between synchronous and asynchronous lectures was quickly noted. In the synchronous classroom the discussion is single threaded as shown in Figure 5. The lecture is interrupted by a question and answer discussion. The discussion is summarized and the lecture continues.

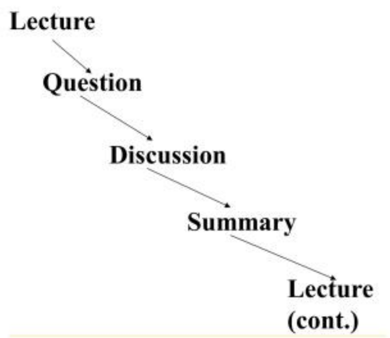

Figure 5 Synchronous thread

This sequential thread is impossible in the asynchronous classroom because of the time delays. Consequently, the lecture is as before, but once the question is asked, the discussion has to be taken off-line and conducted in an asynchronous manner. This leads to a multi-threaded discussion as shown in Figure 6. The implementation of the multi-threaded discussion is via an asynchronous bulletin board, one example of which is shown in Figure 7.

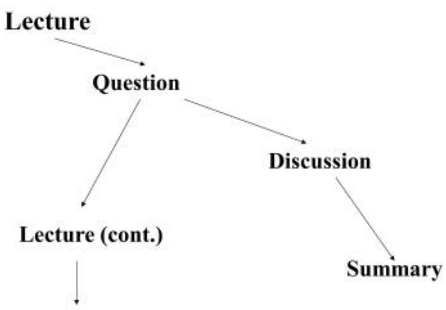

Figure 6 Asynchronous thread

3.3 The different technology for recording the lectures

Recording a lecture is simpler than it sounds[8]. Several readily available low cost software packages for PC and smart phones provide that capability. The approach for recording a lecture is the same as that used for making it in the classroom. The instructor goes through the presentation and records what would have been said in the classroom. Un-

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[6] Many of the students needed the required class to graduate that year and if they were precluded from the class they would have to wait a year to graduate. This would have been unfair so the instructor allowed them into the class and then had to redesign the pedagogy to cope with the large number of students.

[7] The solution was to move the lecture out of the classroom time.

[8] Pun intended.

like in the classroom, the instructor can then review and edit the lecture before the students get to experience it.

The literature review was unable to locate any requirements for the need to see the lecturer during the lecture. There were no answers to questions such as 'was it really necessary to see the instructor or were PowerPoint slides and a picture good enough'? Recognising the similarity between a classroom and a conference presentation, experiments showed that when the lights are down in the conference room, the delegates focus on the presentation and there is little non-verbal communication from the presenter. If the presenter chooses to take questions at the end of the talk, there is no difference between her delivering the presentation synchronously or asynchronously. There thus seems to be no requirement to see the presenter during the presentation, just the presentation graphics.

Figure 7 Asynchronous discusssion forum

Student's comments on the difference between the recorded and live presentations were mainly that they couldn't interrupt the recorded presentation with a question. This was the same response to the same question posed to the audience in the first demonstration/experiment at the INCOSE symposium in Vancouver in 1998 (Kasser and Weiskopf, 1998) when the presenter surprised the session attendees with a pre-recorded presentation. When the pre-recorded presentation began (see Figure 8) the presenter at the podium raised a soft drink can to his lips and drank from it. When the audience noticed that something was not correct, he stepped out of the room for a moment. The first 1998 asynchronous online classroom pre-recorded asynchronous lecture:

- Used PowerPoint for the knowledge video.
- Comprised individual audio (wav) files for each slide which allowed changes to be made to parts of the lecture without having to re-record the entire lecture.
- Incorporated a picture of instructor on each slide.
- Used Real media (rm) format
- Lasted 55 minutes, see Table 1.
- Only needed 3.3 Mbytes of storage space.

By 2010, the pre-recorded asynchronous lectures:

- Still used PowerPoint for the knowledge video.
- Used a single MP3 file for the lecture audio.
- Still incorporated a picture of instructor on each slide.
- Needed up to 10 Mbytes for the audio file alone.

Figure 8 Title slide from first INCOSE pre-recorded presentation

In 2015, the pre-recorded asynchronous lectures:

- Used a number of MP4 video files for the video and audio, each 10 to 20 minutes in duration.

Table 1 Pre-recorded lecture times (minutes)

	CSMN648	SysEng412		SDM5004				MT5014
Session	**1998**	**2010**	**2011F**	**2013**	**2011**	**2012**	**2013**	**2014**
1	55	N/A	19	N/A	N/A	N/A	N/A	N/A
2	47	N/A	39	35.5	46	38	38	30
3	22.5	25.5	34	9	35	37	42	41
4	51.5	6	7	28	6	7	12	10
5	36.5	34	37	24	41	35	34	33
6	38	11.5	20.5	20	15	20	22	21
7	N/A	20	31	46	28	30	30	25
8	28	N/A	7	49	N/A	3	5	5
9	50.5	35.5	74	32	39.5	79	60	78
10	61.5	20	25	43	23	24	24	24
11	30.5	52	51	59	39	51	51	50
12	34	35	27	22	36	25	25	25
13	22	20.5	19	N/A	20	19	19	15
14	N/A	6	9	N/A	6	9	9	9
15	N/A	20	24.5	N/A	28	24	26	25

- Showed the talking head of the instructor as well as the PowerPoint slides.
- Needed 49GB of storage for one MP4 file.
- Were (some of the lectures) uploaded to YouTube[9].

It seems that 17 years of advances in the state of the art have increased the bandwidth and storage needs but have not added much to the basic lectures. The use of technology is vendor-driven based on what is available, rather than being based on requirements. This is where systems engineering can help the domain. Research into the nature of the requirements is needed.

4 The architecture of the balanced classroom

The architecture of the balanced classroom is shown in Figure 9. It contains a mixture of subsystems from two cognitive theories of learning: lecture-centric (objectivist) and exercise-centric (constructivist) (Jonassen, 1991)[10]. Briefly consider each of the following subsystems:

1. The lecture discussed in Section 4.1.
2. The flipped classroom discussed in Section 4.2.
3. The knowledge readings discussed in Section 4.3.
4. The exercises discussed in Section 4.4.
5. The assessment discussed in Section 4.5.
6. Feedback discussed in Section 4.6.

4.1 The lecture

- Can be delivered in real-time in the face-to-face or distance mode classroom or pre-recorded for viewing before the session begins in what has become known as the "flipped classroom".

[9] E.g. those on https://www.youtube.com/channel/UCVBNs9VpnUp6QfytbqzJ96g.

[10] The objectivist approach is based on the assumption that there is a real, objective, and knowable world, and that the instructor's primary duty is to convey that knowledge to the students. The constructivist approach, on the other hand, is based on the assumption that knowledge is constructed by the learner, that learning is active and collaborative and that the instructor's primary duty is to provide a context whereby the student can discover his or her own "constructed" knowledge.

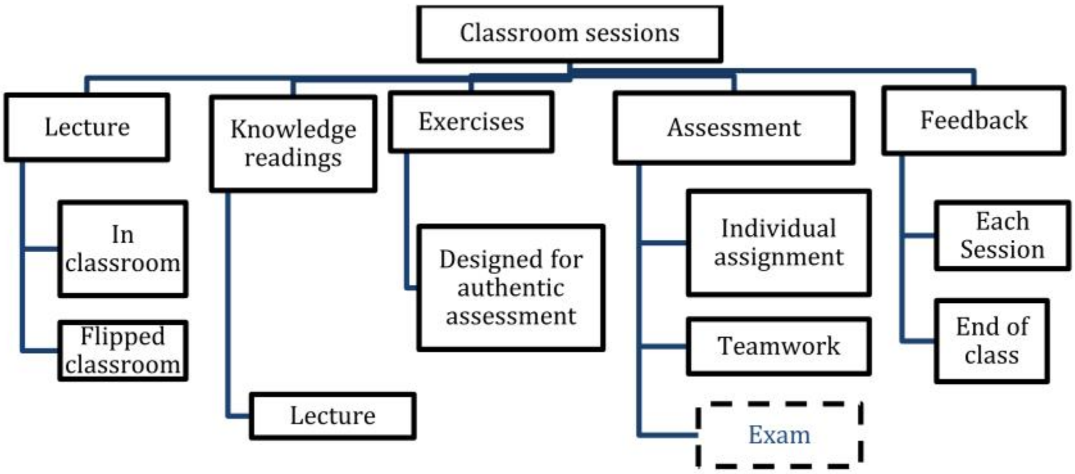

Figure 9. The balanced classroom (integrated system)

- Can summarise session material, highlight the main points and add additional material pertinent to the session.
- Should contain knowledge **not** in the readings. If the lecture summarises the readings, the students will tend treat the lecture as providing a summary of the readings and tend not read the readings themselves[11].
- May be, or may include, a live or virtual guest speaker. For example Professor Derek Hitchins provides some interesting and educational videos about systems engineering on his web site (www.Hitchins.net)[12] and on YouTube.
- May last as long as the students are willing to listen to it provided issues with student attention span discussed in Section 2.6 are addressed.

4.2 The flipped classroom

The flipped classroom is:

- Based on using a pre-recorded video of the lecture.
- Represented in Figure 10 (CIT, 2014).
- A face-face classroom and an online classroom session in which the:
    1) Instructor pre-records the lecture and uploads it to the class web site.
    2) Students (are required to) view the lecture before the classroom session.

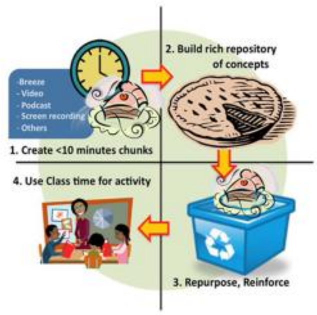

Figure 10 Representation of a flipped classroom (CIT, 2014)

Time saved by not lecturing in the classroom session is to be used for exercises and other participative activities. However, the flipped classroom is a non-systems approach to improving the learning environment, and suffers from at least two defects since the pre-recoded video lecture is:

1. A lecture which is the worst way of teaching something as shown by the data summarised in Figure 1.
2. Based on the incorrect assumption that all the students will view the lecture before class. Unfortunately, experience has shown that students treat the pre-recorded lecture

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[11] Over the years, several students have requested (the Cliff Notes) summaries of the lectures to save them to listen to the full lecture.

[12] In one class session he was even available by prior arrangement to accept and respond to questions by the students after the presentation.

in a similar manner to the way they treat the traditional readings; some read the material ahead of class and some do not, where:

1) Good students interested in the topic do tend to view the lecture before the class.
2) Poor students who need to view the lecture before class tend not to view the lecture before the class[13.]
3) Students who expect the instructor to tell them everything they need to know to pass the class in the classroom tend not to view the lecture before the class.

Most lectures in Massive Open Online Classes (MOOCS)[14] tend to be shorter than 10-15 minutes. This seems to correlate to the attention span limit in Figure 4. However, there is a big difference between a lecture in the classroom and a pre-recorded lecture, namely the students are in control in the pre-recorded environment. They can start and stop the lecture at will according to their individual attention span, interruptions and other distractions. Consequently, as long as the lecturer does not drone on and on, talking about a single slide and changes slides every minute or so to reset the attention span, there does not seem to be a minimum lecture time requirement. For example, as summarised in Table 1:

- CSMN 648 at UMUC was an asynchronous online class. The first year the class ran with pre-recorded lectures was in 1998. The lectures ranged from 22 to 61.5 minutes with an average time of 38.36 minutes. Student feedback was positive, they liked the ability to replay the lectures and listen while commuting to work.
- Almost two and a half decades later, the pre-recorded lectures in the online Missouri University of Science and Technology (MS&T) SysEng512 class and the face-to-face MT5014 and various iterations of the face-to-face SDM5004 at NUS ranged between 6 and 79 minutes. Student feedback was also positive, the students with English as a second language specially liked the ability to replay the lecture.
- The first two lectures in SysEng412 were synchronous and were delivered in real time. However, when problems were reported with the audio and the technical support indicated that it was a common problem with instructors outside the continental USA, the problem of improving the quality of the lectures was dissolved by prerecording them as per CSM648 twenty five years earlier but using a different technology.

There is one advantage to chunking the lecture in a number of files. It allows individual chunks to be updated each time the class runs if the content:

- Becomes out-of-date.
- Needs to be clarified or otherwise updated for any other reason

4.3 The knowledge readings

The knowledge readings (Kasser, 2013):

- Provide the students with the best way to learn according to Figure 1.
- Overcome the situation in which the students do not read the material ahead of time.
- Require the students working in teams, to read the material assigned to the session before the session and present:

    1) A summary of the reading.

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[13] Tested in practice by loading the lecture as PowerPoint slides and MP3 audio files. When instructions for the weekly exercises and assignments were inserted in the audio portion of the lecture some students did know about the instructions.

[14] Based on a limited sample of Coursera MOOCs.

Table 2. Subsystem contributions to the ability to understand, manage, and solve technological problems

Ability	Lecture	Exercises	Knowledge readings
Multiple solutions to a problem/ requirement	Listened	Experienced	Experienced examples
Oral communications	-	Experienced	Experienced
Graphical/pictorial communications	Received	Experienced	Experienced
Ability to handle open-ended/ill-defined problems	-	Experienced	-
Systems thinking	Listened	Went beyond	Went well beyond

2) A list of main points.
3) A description of one of the main points.
4) Comments and reflections on the knowledge in the readings.

- Enable the instructor to correct any misinterpretations as they arose rather than find out something was misinterpreted in the assignment or examination at the end of the class.
- Provide three of the five top aspects of the engineering design process that best equip secondary students to understand, manage, and solve technological problems (Wicklein, et al., 2009) as shown in Table 2.
- Allow students to exercise cognitive skills at levels 3-6 of the upgraded version of Bloom's taxonomy shown in Figure 2.
- Absolved the problem of designing exercises to allow the students to progress through the six levels of the updated Bloom's taxonomy shown in Figure 2 This is because the treatment of the knowledge readings advances the students through the higher levels of the updated Bloom's taxonomy while the exercises only need to be designed for the lower levels. However, a thinking subsystem component was still added to the exercises as discussed in Section 4.4.
- Provide students with the opportunity to practice presentation skills in an Authentic Learning Environment and obtain feedback on both content and style.
- Demonstrate to the students that different people perceive information differently.
- Allow the students the freedom to contribute to the learning via their own learning style. For example, those that prefer:
  - ***Reading*** can read the material.
  - ***Hearing*** can use voice to text technology to listen to the readings.
  - ***Interaction*** can do so within their team and the full class discussion following the set of presentations in each session.
  - ***Researching and self-seeking*** can do so.

4.4 The exercises

The exercises:

- Are designed so that the students:
  - Apply the knowledge from the session to produce a product (the presentation); namely the lower levels of the updated Bloom's taxonomy.
  - Have to think about, and present, what they have learned in doing the exercise by virtue of the exercise requirement to present a 'lessons learned' element; namely the higher levels of the updated Bloom's taxonomy.
- Take place in the context of an authentic representation of workplace and consequently are designed to comply with the requirements for an Authentic Learning Environment listed in Section 2.9. For example, in the first half of the project management class (SDM5004), the students developed the staffing, cost and schedule estimates for

an information technology system upgrade project. In the second half of the class the students had to deal with the effect of "events"[15]. Typical events were:

- Company won a major contract for a new and exciting project, 50% of all technical and managerial staff applied for transfer to new project.
- Customer's budget has been reduced by 25% for the rest of project.
- Project manager was severely injured in automobile accident and was on medical leave for ten time periods[16].
- Poor engineering resulted in delay of five time periods in the task requiring the most time.
- Poor engineering resulted in delay of five time periods in the most costly task.
- Innovative engineering reduced project costs by 10%.
- Vendor/manufacturer of the most critical subsystem went bankrupt and cannot deliver.

As a second example, in the systems engineering class some of the sessions cover the states of the system lifecycle. The exercises in those sessions require the students to perform the activities that systems engineers do in those states of the system development process in the real world.

- Provide the remaining two of the five top aspects of the engineering design process that best equip secondary students to understand, manage, and solve technological problems (Wicklein, et al., 2009) as shown in Table 2.
- Provide the ability to handle open-ended/ill-defined problems (Wicklein, et al., 2009) and systems thinking by the nature of the structure of the exercise by often requiring students to define problem first before mitigating it[17]. For example in the systems engineering class in the Defence domain, an exercise begins with a short video of a military Unmanned Aerial Vehicle (UAV) operational scenario followed by the statement, "*The UAV needs to be improved, brainstorm the situation and propose improvements*". The students then have to decide which aspect of the UAV to improve, hence formulating their problem. One interesting, informative and educational (to the students) outcome is that different teams formulate different problems showing the need for frequent discussions between the customer and the developer.
  - Have multiple acceptable solutions rather than a single correct solution.
  - Require application of domain knowledge and cognitive skills.
  - Are sized for the required workload; the time the students are expected to allocate to the session[18].
  - Can take place inside the classroom session or outside the classroom session depending on the delivery mode.

4.5 Assessment

In a postgraduate class the emphasis shall be on the application of knowledge; critical thinking and the updated Bloom's taxonomy levels 3 and above, rather than on levels 1 and 2 (memorization). The assessment in the balance classroom is in three parts based on:

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[15] Not typically taught in project management classes which focus on creating the plans.

[16] The generic 'time period' may be a day, a week or a month depending on the project. The students convert the time period as appropriate.

[17] The feedback from the first exercise in a class often contains complaints of 'vagueness' in the exercise instructions. By the end of the class there are no complaints of vagueness. So, either the students have learnt to deal with vagueness or they have given up complaining.

[18] Although the students generally put in more time, at least in the early classes

Table 3. Grading based on cognitive skills according to the modified Bloom's taxonomy

Grade	Taxonomy level		Ability being tested	Demonstrating skill by …
A+	6	Creating	Can the student create a new product or point of view?	Assembling, constructing, creating, designing, developing, formulating, writing
A	5	Evaluating	Can the student justify a stand or decision?	Appraising, arguing, defending, judging, selecting, supporting, valuing, evaluating
B+/B	4	Analysing	Can the student distinguish between the different parts?	Appraising, comparing, contrasting, criticizing, differentiating, discriminating, distinguishing, examining, experimenting, questioning, testing
B-	3	Applying	Can the student use the information in a new way?	Choosing, demonstrating, dramatizing, employing, illustrating, interpreting, operating, scheduling, sketching, solving, using, writing
C+	2	Understanding	Can the student explain ideas or concepts?	Classifying, describing, discussing, explaining, identifying, locating, recognizing, reporting, selecting, translating, paraphrasing
C	1	Remembering	Can the student recall or remember the information?	Defining, duplicating, listing, memorizing, recalling, repeating, reproducing, stating

1. Individual performance during the semester.
2. Teamwork in the exercises and knowledge readings.
3. An individual final examination.

The correspondence between the updated Bloom's taxonomy levels, the ability tested in the knowledge readings, exercises and assignments is shown in Table 3 adapted from Overbaugh and Schultz (Overbaugh and Schultz, 2013). The balanced classroom assignment required the students to write an essay containing both descriptive (Declarative knowledge) and critical thinking (Conditional knowledge) elements. In most classes although students were given the opportunity to submit a draft for comment and review before submitting a final version for grading, not every student did so[19]. Students demonstrating the lower levels of cognitive skills also seem to turn in incomplete assignments (which contribute to the low grade due to lack of content to assess) even though they had been told in several ways in different sessions what content the assignment needed to cover.

If examinations are used they shall use well-written multiple choice questions which require the students to exercise the higher level cognitive skills (Conditional knowledge discussed in Section 2.7).

4.6 Feedback

Feedback from the students to the instructor takes place the form of:

1. The traditional end of class student evaluation.
2. Sessional feedback.
3. Comments on content and style of student presentations.

Consider each of them.

- ***The traditional end of class student evaluation:*** which has evolved into an online survey tool providing the students with a number of questions. The students respond to each question on a 5-point Likert scale. The survey at NUS also requests free-form comments about the class and the instructor. Other open ended questions the author has used in classes and workshops outside NUS include:

[19] In one class, 35 out of the 42 students in the class also did not avail themselves of the opportunity.

- What was the best part of the workshop?
- What was the worst part of the workshop?
- The three most useful things I learned were …
- The least useful thing I learned was …

The answers to these questions provide valuable information leading to changes in the subsequent iteration of the class/workshop.

- ***Sessional feedback:*** The author was introduced to this form of feedback in a graduate teaching workshop at the George Washington University in about 1989. At the end of each session the students are asked to take a small piece of paper and without writing their name or any identifying information, write down what they thought was the:
  - **B**est thing about the session.
  - **W**orst thing about the session.
  - **M**issing: something they expected but was not there.
  - **Q**uestion(s) that they did not ask during the session.

  The students are also told that if nothing comes to mind in each category within 10 seconds, to leave it blank. The instructor collects the papers and types up the responses before the following session. This form of feedback is multi-purpose. For example, it:
  - Allows students who process information slowly to ask questions at the end of the session.
  - Sometimes shows that certain topics are both “best” and “worst” as perceived by different people.
  - Can prompt the instructor to improve parts of the session where the students had problems understanding the knowledge to make the subsequent iteration of the class more effective.
- ***Comments on content and style of student presentations*** have been discussed above in Section 4.3 for the knowledge readings and Section 4.4 for the exercises.

5 The three parts of each session

The three parts of each classroom session are discussed as follows.

1. Pre-session activities in Section 5.1.
2. In-class activities in Section 5.2.
3. Post-session activities in Section 5.3.

The post-session activities from one session may overlap the pre-session activities for the subsequent session.

5.1 Pre-session activities

The pre-session activities include:

- Reading the session material.
- Viewing the pre-recorded lecture.
- Preparing the knowledge reading presentations.

5.2 In-class activities

The in-class activities generally follow the following six-part sequence as of the second class meeting/session.

1. ***Discussion on sessional feedback from previous session:*** opens the class. The instructor shares the BWMQ feedback from the previous session and answers any questions that were posed[20]. Starting the class session in this manner also provides the opportunity to summarise the previous session as a lead-in to the current session.
2. ***Exercise presentations:*** the student teams present their responses to the exercises. The instructor immediately provides feedback as to the good and bad points and a grade. When each team has presented, the instructor leads a brief discussion comparing the presentations.
3. ***A short break:*** about ten to fifteen minutes, roughly half way into the session.
4. ***Knowledge readings:*** summarize the knowledge for the session. The instructor comments on and grades each presentation as soon as it is made. When each team has presented, the instructor leads a brief discussion comparing the presentations.

The students in each class typically have a different mixture of cognitive skills. The grading[21] performed according the information in Table 3 tends to reflect the behaviour of the students observed in the knowledge and exercise presentations, and interaction in the question and response dialogues. It was interesting to see the different students demonstrate the characteristics of the five types of systems engineers (Section 2.4). For example, the grades in one class where about half the students did not demonstrate the higher order cognitive skills were as shown in Figure 11. In another class where most of the students only demonstrated remembering and understanding (Taxonomy Levels 1 and 2) levels the grades were as shown in Figure 12.

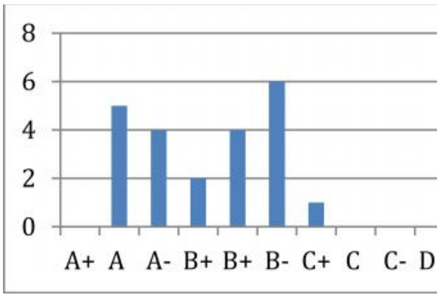

Figure 11 Class demonstrating split cognitive skills

Each presentation in each session differs; illustrating that there can be more than one correct/acceptable solution to a problem and there can be more than one way to satisfy a requirement.

5. ***The Lecture:*** The pre-recorded lecture was made available on the class website prior to the classroom session. However, sometimes students have questions on the material and sometimes there is intellectual property or other content that must not be uploaded to the web site but may be used in the classroom. So, the lecture is delivered in the classroom by presenting the PowerPoint slides silently, advancing the slides and pausing about two to five seconds on each slide and asking the students to call out when they have a question. When a question is posed, the instructor answers it and there may also be some comments and additional questions from other students. The instructor can also add a verbal comment to a slide that links the slide content to something that was presented by the students in an earlier exercise or knowledge reading presentation.

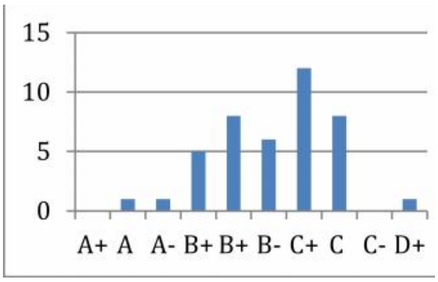

Figure 12 Class demonstrating mostly lower level cognitive skills

6. ***Requesting the sessional feedback for the session:*** This is not done in the last session.

[20] Having had some time to think about the question and answer.
[21] The individual grades are made up from a combination of team work and an individual assignment.

5.3 Post-Session activities

The post-session activities include

- Doing the team exercise for the session.
- Preparing the exercise presentation to be made at the following session.

6 Incorporating the three types of knowledge

The pedagogy of the balanced classroom incorporates all three types of knowledge mentioned in Section 2.7. The students demonstrate their:

- Memorization of Declarative knowledge via the knowledge readings.
- Mastery of Procedural knowledge in what they do in the exercises.
- Mastery of Conditional knowledge by how they do the exercises and their reflections on what they did and learnt in the exercises.

The students exercise their higher order cognitive skills by meeting the exercise requirement to reflect on the content of the knowledge presented in the knowledge reading and what they learned from the exercises. In many instances while they realise they are doing a lot of work, they don't realise what they have done and what they have learnt until it is been pointed out to them in the summary session at the end of the semester.

7 Results

The balanced classroom was used in its current format in postgraduate classes in project management, systems engineering and technology and innovation management at NUS in 2013 and 2014. Some of the observations are:

- Team presentations in the same exercise and knowledge reading in each session differ illustrating:
  - There can be more than one acceptable solution to a problem.
  - There can be more than one way to satisfy a requirement.
- Students misuse bar charts, line graphs or pie charts and need to be shown when to use which type of chart. By comparing the information presented in the different charts students soon pick up on when to use which chart.
- Some students don't seem to be able to make connections between the different elements of the knowledge they are learning. They don't seem to be able to see connections between readings on the same topic, or between readings from the current session and readings from earlier sessions.
- Student presentations provide excellent 'learning opportunities' based on the mistakes the students make in content, style and format[22].
- Students like feedback on both what was good **and** what was bad.
- The quality of presentations by the different student teams improved as the semester progressed since better techniques for presenting information used by one team were picked up by other teams.
- The instructor can point that learning has taken place by showing the students how and why, with to reference to changes from their earlier presentations.
- Student reactions have been very positive once they overcame the initial shock of the different pedagogy[23].
- The post-class feedback was very positive on both the pedagogy and the knowledge

[22] Students can make very innovative mistakes that even good instructors would not predict.
[23] These students have mostly come from a lecture-centric paradigm.

Table 4 Class A extract from student evaluations

Q	Items evaluated	Faculty member average score	Department Average score	Faculty average score
1	The teacher has enhanced my thinking ability.	4.333	4.142	3.959
6	The teacher has helped me understand how to apply knowledge.	4.333	4.089	3.947
7	The teacher has enhanced my ability to learn independently.	4.333	4.078	3.950
8	Overall the teacher is effective.	4.333	4.126	3.987

Table 5 Class B extract from student evaluations

Q	Items evaluated	Faculty member average score	Department Average score	Faculty average score
1	The teacher has enhanced my thinking ability.	4.500	4.205	3.958
6	The teacher has helped me understand how to apply knowledge.	4.375	4.100	3.946
7	The teacher has enhanced my ability to learn independently.	4.500	4.090	3.960
8	Overall the teacher is effective.	4.625	4.214	3.982

the students feel they have gained. The comments are summarized as, "*It was a lot of work, but it was well-worth it*"[24].

- Student feedback is that the classes are changing the way they think. Two extracts from student evaluations of two different classes are shown in Table 4 and Table 5. Table 4 is from a class on the systems approach to technology and innovation management in which the students were taught to think holistically. In the example, the class size was 18 and the number of students responding was 3 (17%). Table 5 is from a class on the systems approach to project management. In the example, the class size was 35 and the number of students responding was 8 (23%). So in this small sample of two classes on two very different topics, some of the students evaluated the contribution to improving their cognitive skills as being more effective than the approach used by any other teacher in the faculty.
- The subsystem contributions to:
  - The ability to understand, manage, and solve technological problems is summarized in Table 2.
  - Exercising the cognitive skills in Bloom's taxonomy is summarized in Table 6.
  - Creating an Authentic Learning Environment is in the exercise and knowledge readings.

The compliance matrix showing how the combination of the subsystems of the balanced classroom complies with to the system requirements is shown in Table 7.

8 Summary

This paper discussed applying systems engineering to the problem of optimising postgraduate education. According to the literature, previous research on systems engineering education and curriculum design focused on the nature of the

Table 6. Subsystem combination to Bloom's taxonomy

Bloom's taxonomy		**Lecture**	**Exercises**	**Knowledge readings**
6	Creating	-	-	√
5	Evaluating	-	-	√
4	Analyzing	-	-	√
3	Applying	-	√	-
2	Understanding	Unknown	√	√
1	Remembering	Listened	√	√

[24] It is difficult to distinguish between the comments on the pedagogy and the instructor.

Table 7 Compliance Matrix

Requirements	Lecture	Knowledge readings	Exercises	Individual assignment
Knowledge of subject domain	Poor	Best	In between	Repeated
Multiple solutions to a problem/ requirement	Listened	Experienced additional examples	Experienced	Not seen
Oral communications	-	Experienced	Experienced	-
Graphical/pictorial communications	Received	Experienced	Experienced	-
Ability to handle open-ended/ill-defined problems	-	Depends on external readings	Experienced	Depends on assignment
Holistic/Systems thinking	Listened	Went well beyond	Went beyond	Depends
Cognitive skills	-	5 out of 6 levels in Bloom's taxonomy	Lowest 3 levels in Bloom's taxonomy	Depends
Teamwork	Some	Experienced	Experienced	No
Authentic Learning Environment	-	Experienced	Scenarios	-

knowledge to be taught, and tended to ignore pedagogical issues. Although the research and development lasting from 1998 to 2015 covered both the content and the pedagogy, this paper:

- Focused only on the pedagogy.
- Suggested that instead of adopting a single technique such as the 'flipped classroom', a number of teaching techniques shall be used together as subsystems in an interdependent manner blending them to enhance the learning experience.
- Described a balanced classroom which mixes a number of previously tested teaching and learning subsystems interdependently in a synergistic manner.
- Concluded with a brief summary of the results of using the balanced classroom in three different classes in 2013 and 2014.

The contributions of the balanced classroom to teaching and learning are:

1. It is the first time that all the subsystems have been used (integrated) together interdependently as a system.
2. It overcomes the major defects in the 'flipped classroom'.

Section 2 provided some of the requirements for the balanced classroom developed during the research. Section 3 summarised some of the research and development leading up to the balanced classroom. Section 4 described the architecture and subsystems in the balanced classroom. Section 5 discussed the three parts of each session how the balanced classroom is used. Section 6 showed how the three types of content free knowledge are incorporated into the balanced classroom. Section 7 shared some of the results using the balanced classroom in three different classes in 2013 and 2014.

9 Conclusions

The conclusions are, the balanced classroom:

1. Is the result of applying systems engineering in the education domain.
2. Meets the requirements summarized in Section 2.
3. Is a fun teaching and learning experience.
4. Advances the state of the art in the educational domain beyond flipped classrooms.
5. Needs a teacher who understands the knowledge being taught. Instructors who teach the textbook by rote would not perform well in the balanced classroom.

6. May be used both in the traditional classroom and in online synchronous and asynchronous classrooms.
7. Is suitable for teaching postgraduate subjects other than systems engineering.

10 Further research

Converting a traditional experience-based class to the balanced classroom format is a non-trivial task. The problem of converting a degree program containing a set of stand-alone classes, a man-made system, into an integrated program is a complex problem and will require the program director to be a systems engineer. Creating a generic process than can be applied across institutions is an even more complex problem worthy of further research since it will increase the effectiveness of teaching and learning systems engineering globally.

11 Biography

Joseph Kasser has been a practicing systems engineer for 45 years and an academic for about 18 years. He is a Fellow of the Institution of Engineering and Technology (IET), a Fellow of the Institution of Engineers (Singapore), an INCOSE Fellow, the author of "*Perceptions of Systems Engineering*", "*Holistic thinking: creating innovative solutions to complex problems*", "*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. He is a Certified Manager and holds a Certified Membership of the Association for Learning Technology (CMALT). He also started and served as the inaugural president of INCOSE Australia and served as a Region VI Representative to the INCOSE Member Board. He has performed and directed systems engineering in the UK, USA, Israel and Australia. 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 class in systems engineering as a Leverhulme Visiting Professor at Cranfield University. He is currently a Visiting Associate Professor at NUS.

12 References

Allen, M., *Smart thinking: skills for critical understanding and writing*, Oxford University Press, 2004.

ASEA, *Engineering Education for a Changing World*, American Society for Engineering Education, 1994.

Biggs, J., *Teaching for Quality Learning in University*, Society for Research into Higher Education and Open University Press, 1999.

Brown, D. E. and Scherer, W. T., *A comparison of systems engineering programs in the United States*, Systems, Man and Cybernetics, Part C, IEEE Transactions on 30 (2000), no. 2, 204 - 212.

CIT, Courseware & Flipped Classroom, National University of Singapore, 2014, http://cit.nus.edu.sg/courseware-emodules, accessed on 8 July 2015.

Dale, E., *Audio-visual methods in teaching*, Dryden Press, New York, 1954.

Eichhorn, R., Developing thinking skills: critical thinking at the army management staff college, 2002, http://www.amsc.belvoir.army.mil/roy.html, accessed on April 11, 2008.

Enger, K., "Master Program 2013 - 2016 Systems Engineering," F. o. Technology (Editor), Buskerud University College, Kongsberg, Norway, 2012, p. 12.

Facione, P. A., Facione, N. C. and Giancarlo, C. A., *The Disposition Toward Critical Thinking: Its Character, Measurement, and Relationship to Critical Thinking Skill*, Informal Logic 20 (2000), no. 1, 61-84.

Gharajedaghi, J., *System Thinking: Managing Chaos and Complexity*, Butterworth-Heinemann, Boston, 1999.

Gordon G. et al., *A Contingency Model for the Design of Problem Solving Research Program*, Milbank Memorial Fund Quarterly (1974), 184-220.

Herrington, J., Reeves, T. C., Oliver, R. and Woo, Y., *Designing Authentic Activities in Web-Based Courses*, Journal of Computing in Higher Education 16 (2004), no. 1, 3-29.

Jonassen, D. H., *Objectivism versus Constructivism: Do We Need a New Philosophical Paradigm?*, Educational Technology, Research and Development 39 (1991), no. 3, 5-14.

Kasser, J. E., *Using Systems Engineering to Create and Guide a Successful Student Software Engineering Project Class when the Instructor is Half-Way around the World*, proceedings of Australasian Conference of the Engineering Management Educators, Wollongong, 2001.

---, *Developing the Requirements for Introductory Courseware for Systems Engineering*, proceedings of the Asia Pacific Systems Engineering Conference, Singapore, 2007a.

---, *Quantitative requirements for the competencies of systems engineers, in Is the systems engineering profession quantitative enough?*, proceedings of the 17th International Symposium of the INCOSE, San Diego, CA., 2007b.

---, *Applying Holistic Thinking to Improving Your Sex Life*, proceedings of the Sixth Israeli Conference on Systems Engineering, Hertzlia, 2011.

---, *Introducing "knowledge readings": Systems engineering the pedagogy for effective learning*, proceedings of Asia-Pacific Council on Systems Engineering (APCOSE) Conference, , Yokohama, 2013.

Kasser, J. E., Hitchins, D. K. and Huynh, T. V., *Reengineering Systems Engineering*, proceedings of the 3rd Annual Asia-Pacific Conference on Systems Engineering (APCOSE), Singapore, 2009.

Kasser, J. E., John, P., Tipping, K. and Yeoh, L. W., *Systems engineering a 21st century introductory course on systems engineering: the Seraswati Project*, proceedings of the 2nd Asia Pacific Conference on Systems Engineering, Yokohama, Japan, 2008.

Kasser, J. E., Sitnikova, E., Tran, X.-L. and Yates, G., *Optimising the Content and Delivery of Postgraduate Education in Engineering Management for Government and Industry*, proceedings of the International Engineering Management Conference (IEMC), St. John's, Newfoundland, Canada, 2005.

Kasser, J. E. and Weiskopf, M., *Systems Engineering to Sydney*, proceedings of the 8th INCOSE International Symposium, Vancouver, BC., 1998.

Lowery, L. L., Use of Teams in Classes, 2002, http://Lowery.tamu.edu/Teaming/Morgan1/sld023.htm, accessed on 6 February 2007.

Mills, H. R., *Techniques of technical training*, Cleaver-Hume Press, London, 1953.

Overbaugh, R. C. and Schultz, L., Bloom's Taxonomy, Old Dominion University, 2013, http://ww2.odu.edu/educ/roverbau/Bloom/blooms_taxonomy.htm, accessed on 13 March 2013.

Paul, R. and Elder, L., *Critical Thinking: learn the tools the best thinkers use - concise ed.*, Pearson Prentice Hall, 2006.

Perry, W., "Cognitive and Ethical Growth: The Making of Meaning," *The Modern American College: Responding to the New Realities of Diverse Students and a Changing Society*, A. W. Chickering (Editor), Jossey-Bass, San Francisco, 1981, pp. 76-116.

Reeves, T. C., Herrington, J. and Oliver, R., "Authentic activities and online learning," *Quality conversations: Research and Development in Higher Education*, A. Goody, J. Herrington and M. Northcote (Editors), vol. 25, Jamison, ACT: HERDS A, 2002, pp. 562-567.

Sage, A. P., *Systems engineering education*, Systems, Man and Cybernetics, Part C, IEEE Transactions on 30 (2000), no. 2, 164 - 174.

Schunk, D. H., *Learning Theories*, Pentice Hall, Englewood Cliff, NJ, 1996.

Wicklein, R., Smith Jr., P. C. and Kim, S. J., *Essential Concepts of Engineering Design Curriculum in Secondary Technology Education* Journal of Technology Education 20 (2009), no. 2, 66-80.

Wolcott, S. K. and Gray, C. J., Assessing and Developing Critical Thinking Skills, 2003, http://www.wolcottlynch.com/Downloadable_Files/IUPUI%20Handout_031029.pdf, accessed on 21 May 2013.

Woolfolk, A. E., "Chapter 7 Cognitive views of learning," *Educational Psychology*, Allyn and Bacon, Boston, 1998, pp. 244-283.

Wymore, A. W., *Model-Based Systems Engineering*, CRC Press, Boca Raton, 1993.