Altered Andragogy: Lessons from Lockdown for Systems Engineering Education

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Abstract
Systems Engineering (SE) is a largely interactive and applied discipline which has been mainly taught via face-to-face tuition. The move to online-only teaching due to the 2020 coronavirus pandemic thus posed significant challenges for SE education. The andragogical strategy involved had to be rethought and redesigned such that key precepts of student learning could be maintained in a way that preserved the depth, intricacy, and richness of the SE discipline. The interdisciplinary approach adopted involved combining a constructivist viewpoint with integrated collaborative and reflective activities, based around inquiry-based learning to facilitate online learning at distance. This pedagogical construct relied on a multidisciplinary and iterative approach to curriculum and module delivery, employing multiple methods to redesign the teaching approach to 'chunk' material into sets that were more readily deliverable in short bursts, and more digestible without face-to-face interaction. This took in revisions to the traditional pedagogical approach to learning, and blended short live online sessions with self-paced tasks, supported by Q&A sessions and 'thought bursts' of key information to summarise key learning points. Learning technology and software tools were used to facilitate and promote interactive and group workshops, which was particularly challenging but proved useful in bridging generational gaps and preferences for certain learning styles. This paper details the andragogical approach taken to wholly online distance learning for SE, reflecting on how successful it was both initially and as it evolved. It also considers how future learning can be successfully facilitated, incorporating the pedagogical lessons learned from the last twelve months.

Keywords: Andragogy, Systems Engineering, Teaching Practice

Introduction

Systems Engineering is a multidisciplinary subject, which "*focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem: Operations, Performance, Test, Manufacturing, Cost & Schedule, Training & Support, and Disposal*" (INCOSE, 2012). As such, it is a practical, applied subject, which relies on the involvement of multiple stakeholders, and is highly interactive in its nature. When teaching the subject, especially at UK level 7 ("What qualification levels mean", 2021), this means that the focus must be on activities that allow students to explore the use of concepts in situations which are as realistic and reflective of real-world scenarios as is possible. In particular, ways must be found to allow the students to address issues such as those listed below:

- Addressing the increasingly complex challenges and problems which we face in engineering and management today.
- Identifying and exploring the root causes of problems.
- Viewing issues and requirements from multiple perspectives.
- Structuring problem thinking, solution development and application across the lifetime of a system or procurement, from concept to retirement.
- Instilling an understanding of how systems engineers, domain engineers and project managers come together as multi-disciplinary teams to develop solutions to real world problems

To do this, systems engineering education has employed a mixture of traditional, lecture-based learning, and experiential, more practical teaching and learning practice. The intention behind this, from an andragogical perspective, is to facilitate student learning of the essential concepts and components of the subject (Bligh, 1998; Bonesso et al., 2015; Garside, 1996), whilst allowing a positive and interactive hands-on experience through experiential application and learning (Pugsley & Clayton, 2003; Illeris, 2007). Cranfield University's Systems Engineering MSc ("Systems Engineering MSc", 2021) achieved this by employing two different types of course module, as described at figure 1 over page. The left-hand side format, labelled 'taught module', describes a standard module in which students are instructed on systems engineering concepts, before being given the opportunity to reinforce their learning through a series of exercises and supervise practical work, both individually and as members of a group. Formative feedback is given at regular points, and a summative assessment is then undertaken post module to test knowledge and the ability to interpret, apply, and reflect. These taught modules were interspersed with 'workshop modules', described by the right-hand format in figure 1, which allow students to apply learning to a realistic real-life scenario or case study, encouraging them to explore the application of systems engineering concepts and models, potentially challenging their validity, and to experience, within reasonable bounds, how systems engineering can bring benefit to business operations. Assessment in the workshop modules is more interactive, taking the form of group presentations, and experiential portfolios, as well as individual reflective assignments. This coverage ensures that multiple faces of student ability are tested, ranging from understanding and being able to rationalise concepts, through applying and evaluating models and techniques, to reflecting upon outcomes, and developing strategies for use and application. It also focuses on the completeness of the educational and learning experience, spans the spectrum of Bloom's taxonomy of educational objectives (Bloom, 1979), and ensures that requirements of level 7 education are met.

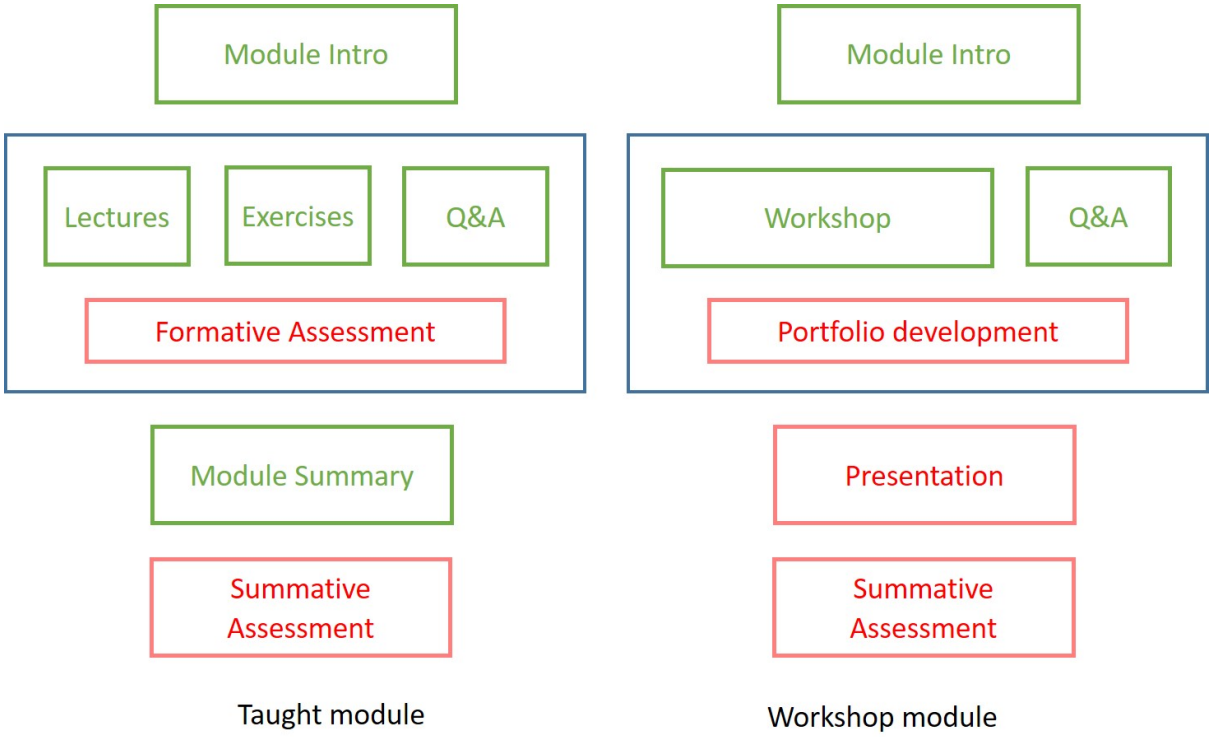

Figure 1: Module Structures

Both types of modules are clearly interactive in design and approach, and as such, received wisdom held that they were best achieved through face-to-face delivery. This idea was tested to the full when the coronavirus pandemic of 2019-20 struck and necessitated that in order to continue delivery of education, all courses had to be moved online. This move, together with associated lockdown and stay-at-home orders, posed several challenges, ranging from finding a suitable delivery mechanism to permit continued delivery, through dealing with alterations to student learning preferences and expectations, dealing with issues around staff and student wellbeing, ensuring continuation of educational offering(s), and coping with factors such a working from home and childcare. This paper describes the andragogical challenges presented by this situation, focusing specifically on the approach developed to maintain course delivery, and explores the lessons learned and what they might mean for systems engineering education in the future.

Online Education and the Challenges for Systems Engineering

The move to online-only teaching and learning delivery forced by lockdown and stay-at-home instructions to contain the spread of the coronavirus pandemic required a rethink of how teaching and learning could be continued and maintained to the required standard to allow award of end qualification. Several factors needed to be considered in this process, notably what teaching mechanisms might be suitable to facilitate purely online learning, and how student needs and learning preferences could be catered to. The type of teaching and learning was important; as certain facets lend themselves more readily to online learning than others. For a more structured learning experience, such as training, students tend to have different expectations than they would of a more exploratory educational experience (Barker, 2014). Table 1 below demonstrates this.

		Training	Education
Delivery Structure		Structured, highly regulated	Less structured, more interactive
Format		Formal Lecture, structured workshop	Lecture and workshop
Teaching style		Formal instruction	Debate, peer workshop
Interaction		Minimal	Expression of opinion
Lecturer view		Taken as authoritative	Challenged through debate
Personality "type"		Untailored	Tailored

Table 1: Student Expectations of Learning Experience (Barker, 2014)

Fry et al. (2009) and Ramsden (2003) suggest that for an educational experience, students have an expectation that there will be a mix of short instructional pieces interspersed with exploratory and interactive group work, or possibly research tasks. Students tend to be more prepared to challenge the accepted wisdom of a scenario or situation, evaluating their own view in comparison to the 'authority' view. As a result, Barker (2014) suggests that "students cycle through the 'relate-create-donate' paradigm advocated by Shneiderman (1998) in which the students interact with others in groups to develop ideas ('relate'), before putting these ideas into practice on a case study or project ('create'), and then extrapolating the learning experience into meaningful and useful contexts in their own wider world ('donate')". Thus, the educational experience is focused upon testing boundaries, and accepting the need for change (Hendry, 1996). For training, however, experience suggests that there is more an expectation of highly structured instruction followed by the undertaking of clearly specified tasks with clearly defined expectations of outcomes (Barker, 2014).

Given the interactive, multiple perspective-centric nature of systems engineering, it might clearly be seen to fall into the educational experience domain as a result of which the more fluid teaching and learning styles required posed significant issues for online delivery. Student learning preferences must also be considered, Fry et al. (2009) suggesting that students can perceive the same teaching in different ways. Table 2 illustrates a categorisation of preferred learning styles proposed by Honey & Mumford (1982). Given these differing learning styles, the employment of a variety of teaching methods is necessary to ensure completeness of understanding and learning experience. Barker (2014) identifies key teaching methods as being: lecturing; facilitated group workshop; self-study and individual research; e-learning; group debate and presentation, and the employment of a combination of these in a varied manner is a good approach to ensuring student involvement and enthusiasm (Ramsden, 2003).

Classifier	Descriptor
Activist	Responds most positively to learning situations offering challenge, to include new experiences and problems, excitement and freedom in their learning
Reflector	Respond most positively to structured learning activities where they are provided with time to observe, reflect and think, and allowed to work in a detailed manner
Theorist	Respond well to logical, rational structure and clear aims where they are given time for methodical exploration and opportunities to

	question and stretch their intellect
Pragmatist	Respond most positively to practically based, immediately relevant learning activities, which allow scope for practice and using theory

Table 2: Categorisation of Learning Style (Honey and Mumford, 1982)

Having considered the andragogical needs of education and student learning styles, it is necessary to place these in the context of achieving the delivery of systems engineering delivery online. Having already established that systems engineering is highly interactive and therefore requires a style of education that lends itself to facilitation of group working, discussion, and shared experiential learning, analysis by the Cranfield course team established some key challenges to continued delivery of the MSc in an online world. These are listed below.

- Face-to-face teaching now unachievable
- Different learning needs
- Different learning styles
- Reliance on technology which was (initially) unproven
    - Student access
    - Reliability of IT for teaching

The inability to deliver in a face-to-face manner was perhaps the biggest challenge to continued delivery of the course. Under normal circumstances, exercises, research tasks and longer workshops would be facilitated by giving the students access to physical breakout rooms containing whiteboards, paper, pens and space to discuss and debate real world issues and how to apply systems engineering in that context. This is particularly important to undertaking of the higher-level activities described by Bloom's taxonomy of educational objectives (Bloom, 1979) which are necessary in order to meet the requirements of level 7 education (QAA, 2014). Without the ability to deliver face-to-face, the online teaching delivery simply lacked the flexibility of the face-to-face alternative. Examples of this are that the interactive environment cannot be fully replicated, it can be more difficult to model and share ideas because IT solutions can be more limiting and formulaic (i.e. modelling software can enforce modelling conventions which are unhelpful when trying to characterise a fluid and complex situation). Moreover, the limitations of the IT solution employed could mean that students were not able to fully interact on group work, and not get the full benefit from their learning experience.

The learning needs of students could also be impacted, in that some students suffer from learning difficulties such as dyslexia, which could be negatively impacted by online-only delivery (Gabay et al., 2012; Kormos & Nijakowska, 2017). This required very careful consideration, as university and national/international standards of teaching and duty of care had to be maintained. Special provision of materials, and one-to-one special advice for students had therefor to be factored into the andragogical equation.

A related concept to learning needs is that of learning preference or style. Research has shown that individuals of different gender (Wehrwein et al. 2017), or age (Truluck et al. 1999), for instance, have different learning preferences, and respond better to different teaching methods. As a result, the most suitable teaching method and techniques had to be found to optimise the online learning experience, which created the ned for more frequent review than would perhaps otherwise have been the case. Apart from that, some individuals

simply tend to exhibit a preference for a particular teaching method or learning style (Kharb et al., 2013; Manolis et al., 2013). Examples from experience are that some individuals prefer step-by-step tuition ahead of a structured exercise analogous to the training experience outlined in table 1, whilst others are content to have free rein of a workshop approach to allow them to explore and evaluate ideas, methods, and techniques.

The final problem initially identified by the course team was the reliance upon IT. Several different packages and solutions had to be trialled, appraised, and approved before a consistent and reliable IT solution could be arrived at, and this was found to be disruptive to the teaching and course delivery effort. Particular problems identified were that some students, reliant upon home or personal IT, had difficulty – initially at least – in accessing software packages or programs, and the reliability of the chosen IT solutions varied across time due to the fact that they were often provided by third party vendors who were in some cases developing their offering continually (Gray et al., 1998; "How Covid-19 Has Pushed Companies over the Technology Tipping Point – And transformed business forever", 2021).

Having described the problems facing the online delivery of systems engineering, the next section will describe how the course team approached the design and implementation of an andragogical strategy to allow continued delivery of the Systems Engineering MSc online.

Approach to Online Delivery of Cranfield's Systems Engineering MSc

In order to meet the challenges to online delivery of systems engineering education outlined in the above section whilst being able to continue course delivery, the MSc course team conducted a number of planning meetings in a short period of time in order not to disrupt the intended schedule of module delivery before implementing an incremental approach to delivery and review, adopting the approach illustrated in figure 2 below.

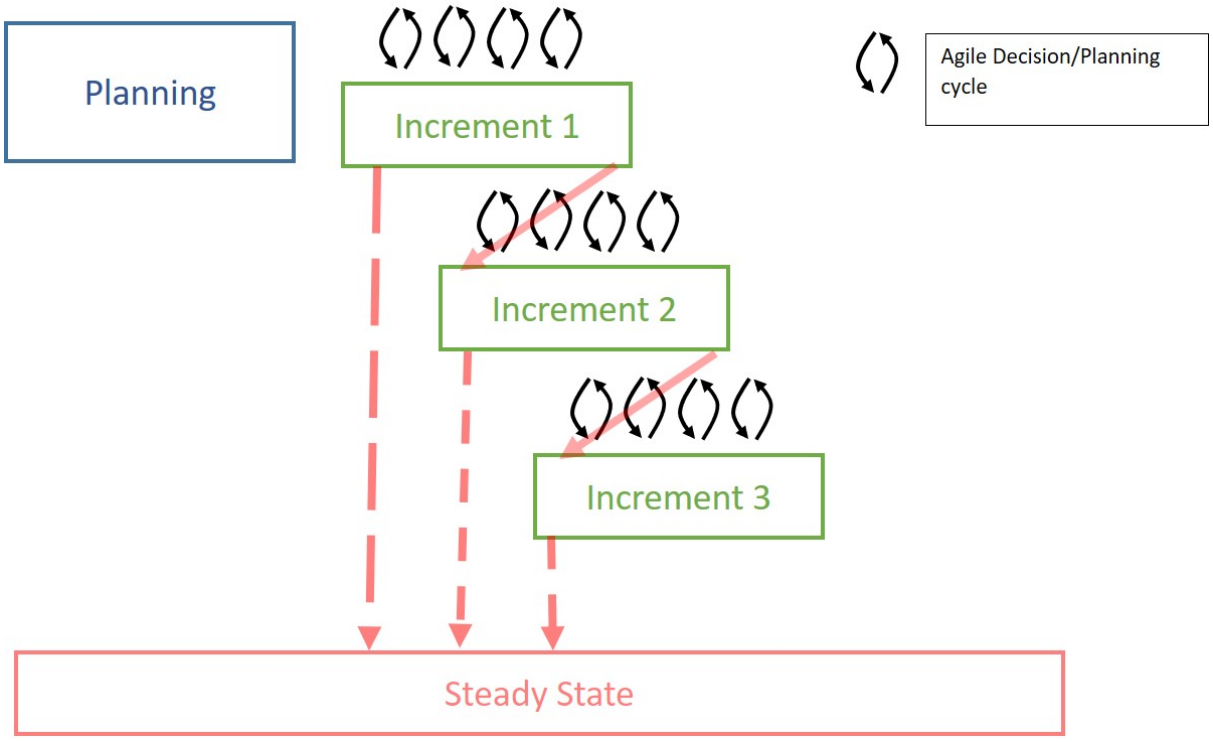

Figure 2: Approach to online course delivery

It quickly became apparent that flexibility in planning the continued delivery, but also the delivery of course modules themselves, would be vital if a successful outcome as to be achieved. The use of resources to facilitate learning would also be important to provide a varied and quality learning experience. Principle among these facilities would be:

- Online direct contact time with students
- Online independent study time for exercises and workshops
- Offline research activities and reflection
- Virtual Learning Environment as a repository for course/module material and as a learning resource

Furthermore, it would be necessary understand how student learning styles and preferences could be best accommodated by which combination of the above points with the teaching methods suggested by Barker (2014): lecturing; facilitated group workshop; self-study and individual research; e-learning; group debate and presentation. How this combination could deliver the required educational package to the requisite standard would also need careful consideration, involving an assessment against Bloom's taxonomy (Bloom, 1979) and level 7 andragogical requirements (QAA, 2014).

The planning conducted by the course team sought to achieve an initial balance of use of facilities to facilitate teaching methods, which was based upon experience of teaching at level 7 and knowledge of existing student learning preferences accrued during pre-coronavirus pandemic teaching delivery. This resulted in the following principal changes to module delivery, noting that delivery differed depending on the type of module identified in figure 1 (i.e. taught or workshop).

- Increased use of Virtual Learning Environment (VLE) as resource for information sharing
- Shorter instructional/lecture sessions
- Increased blend of different learning activities
- Increase in interactive exercise/workshop activities, followed by student briefings, and provision of worked answers
- Increase in amount of formative feedback provided to bolster learning
- Increased use of software to facilitate modelling exercises

It was reasoned that sitting at a computer for periods of time would be uncomfortable for students and teachers alike and would also affect the students' ability to concentrate on the necessary learning. Therefore, shorter, 'punchier' instructional pieces, either by 'live online' mini-lectures, or pre-recorded pieces placed on the VLE were adopted. The latter was thought to be important in that it would allow students to study either at their own pace, or at a more convenient time given other pressures caused by lockdown and work-at-home instructions.

A blend of teaching activities was also employed to ad variety and ensure that learning was reinforced whilst trying to cater for different learning styles and preferences. Methods used varied from module to module but might include a short initial instructional piece followed by a supervised exercise and then an offline research task to extend learning. An increased use of peer-to-peer evaluation, and group presentations was made to ensure student involvement and facilitate feedback. Regular 'live online' Q&A sessions were planned to allow formative feedback, whilst one-to-one student and mentor sessions were offered to provide reassurance and ensure student confidence in their learning. For longer workshops, more regular supervisor input was planned, along with regular 'report back' slots, and

progress reviews if requested by students. Assessment methods were also adapted more toward interactive group presentations and portfolio development, emphasising peer support and joint learning outcomes. In this way, a more complete and inclusive experience for students could be constructed. Use of software was also adopted where it would facilitate common learning across the student cohort and ease the burden of learning remotely. This course planning activity led to the development of a "blended learning toolbox" for online module delivery, as described in the bullet points below.

- Live online teaching sessions
- Self-paced "information packages"
- Interactive workshop segments
- Thought-provoking "mini-segments"
- Live discussion sessions
- Live online Q&A activities
- Peer-to-peer online/offline activities

Course modules were then delivered against the original timescale, butt with increased review both during and after the module took place, as shown in figure 2, in order to ascertain that quality was being maintained, student learning was being successfully facilitated, and that student expectation of learning was being met. There were inevitable teething issues, particularly around use of IT solution, but these were quickly resolved through discussion with Cranfield's IT department, and with minor tweaks on an ongoing basis, delivery achieved a steady state in a satisfactory timescale. Student feedback was sort throughout the delivery process, both informally and at a Student Liaison Committee, which has been run regularly by the course team to canvas student opinion, resolve any issues, and identify improvements that can be made. The process of incorporating that feedback and improving modules for future delivery is described in the next section.

Incorporating Student Feedback and Learning from Experience

Given the revised andragogical concept of course delivery and format devised at relatively short notice described above, a decision was taken by the course team to hold regular review meetings both during and after module delivery to make necessary adjustments and improvements, taking into account experience of delivery methods and student feedback. Feedback was sought as frequently as was practicable and was fed back into the continual review process to improve module delivery and student learning experience as much as possible within the limitations of online-only delivery. A summary of main student feedback to initial delivery of the online course is given in table 3 below.

Feedback topic	Student comment
Online delivery mechanism	Initial teething problems with IT, but once accustomed, could see benefits of "learning from home"
Delivery (teaching) style and learning experience	Liked the idea of shorter segments of instruction, followed by workshops and then provision of worked solution/answers
	Recognised trade-off of not having face-to-face versus freedoms of: • Working from home • Self-paced learning
	Disliked complete lack of face-to-face learning
	Found it hard to make all online sessions

Table 3: Summary of Student Feedback

The course team reacted to this feedback to include voiced-over presentations and thought-provoking "mini-segments" on the VLE to increase flexibility for the students and encourage reflection and further consideration of key systems engineering factors and issues, and a policy of recording all 'live online' sessions was introduced to attempt to accommodate other pressures on students' lives during the lockdown period. Other changes that were made to the course delivery mechanism as a result of the reviews and feedback received are listed below.

- Make Virtual Learning Environment material available earlier
- Ensure 'system test' sessions are programmed ahead of module delivery
- Tailor 'blend' of delivery methods to particular groups of students
- Double staff sessions to add redundancy in case of IT failure
- Continue to focus on frequent review of teaching effort and learning experience

Increasing the material available by the VLE, coupled to making the material available earlier, allowed students to appraise key issues that would be discussed during modules in their own time, and also supported students with learning difficulties who required a longer timescale to understand the information provided. The course team also made efforts to tailor delivery to individual groups of students as a result of consultation and feedback, and these changes were met with significant student approval.

Attempts were then made to increase the resilience of the online delivery mechanism by double-staffing 'live online' delivery so that if one member of teaching staff experienced IT issues, there would be a second member present online to be able to takeover. In addition to this, pre-module 'system tests' were instigated to ensure that students wee able to access necessary IT and teaching resources.

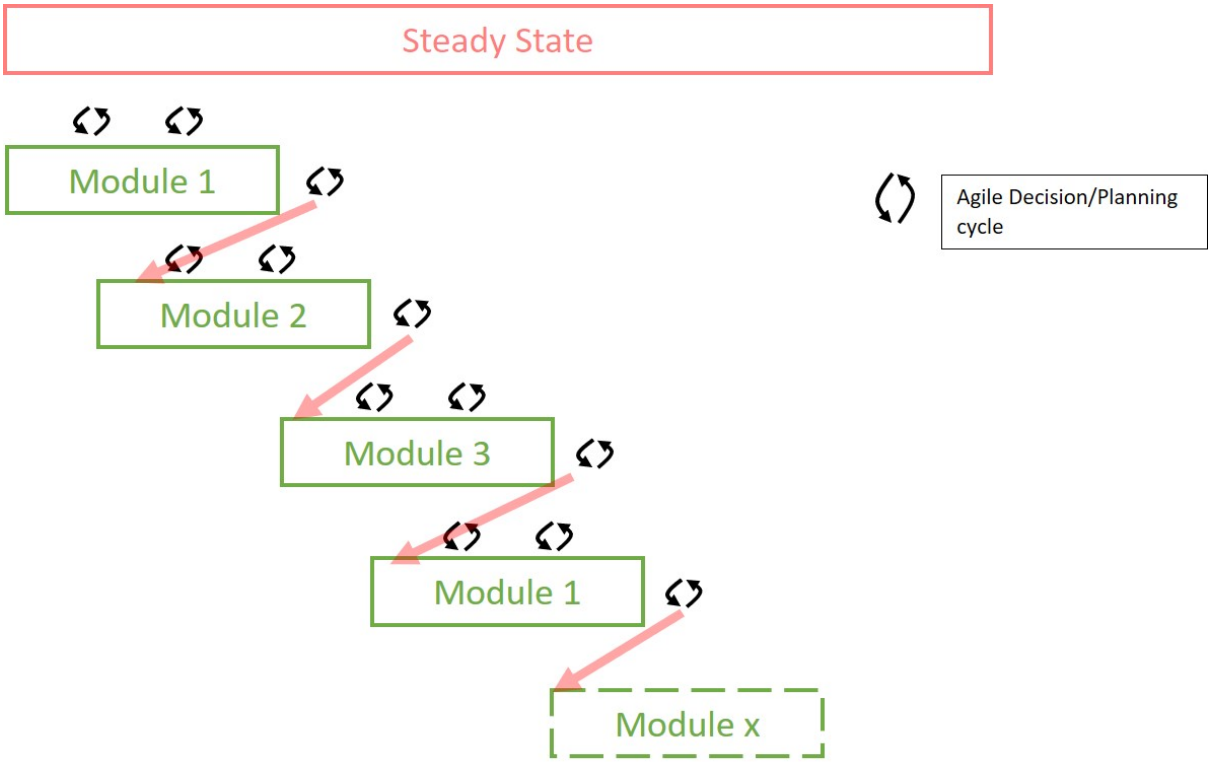

Figure 3: Steady State Delivery of the Online Course

This process of consultation, seeking feedback, regular review and improvement of module delivery allowed reflection upon key lessons, and the extension of the initial approach to online delivery described at figure 2 into a 'steady state' delivery mode described at figure 3. This allowed for module delivery as planned whilst still reviewing and updating delivery at a pace required by the prevailing situation, and sharing best practice and lessons learned across all modules. The lessons learned and improvements identified were disseminated amongst the course team, and also presented to course directors and teaching staff from other courses in order to improve practice throughout the school and wider university such other courses could avoid the issues encountered in delivering the Systems Engineering MSc, and adapt lessons learned for their own courses and modules. The next section will summarise the findings of this paper and make recommendations for future online course delivery based upon lessons learned and described in this paper and will summarise key findings.

Recommendations and Conclusions

This paper has sought to describe how the course team for Cranfield University's Systems Engineering MSc reacted to the instruction to lockdown and stay-at-home as a result of the 2019-20 coronavirus pandemic in order to continue to deliver the MSc course in an online-only manner. The difficulties facing online-only course delivery are described, both generically and from a systems engineering perspective. The course team's response was to hold a series of planning meetings in an extremely short period of time as shown at figure 2 in order to maintain the established schedule of module delivery and limit disruption to students. An incremental approach to delivery, incorporating agile/real-time review and replanning and module update sessions was then implemented in order to maintain effective delivery whilst solving issues such as IT problems in an ongoing manner. In this way, the student learning experience was optimised as far as was possible under the circumstances. Student feedback was sought throughout the process, and key elements of this are detailed at

table 3. This feedback was incorporated into the course planning and review strategy, and along with alterations as a result of other lessons learned resulted in the 'steady state' delivery mode described at figure 3. The whole experience led to a number of recommendations for continued online course delivery, and these are listed below.

- Although Systems Engineering does not lend itself readily to pure distance learning, a blend of online and face-to-face sessions could facilitate successful education
- Back-up staff options are essential to ensure resilience of online teaching delivery and learning experience of students
- Shorter, more impactful, information packages facilitate improved student learning
- Ensure blend of learning activities is appropriately tailored to student learning needs, preferences and styles

The context in which such recommendations are applied is of course important as different courses have different demands – for example, theory-based courses would not necessarily face the some of issues outlined above in that they would not necessarily require a highly interactive andragogical approach to delivery and student learning, whilst other experiential or practitioner courses where interaction and sharing of ideas is a necessary part of the learning experience, might be dealt with in a similar way to the systems engineering example described in this paper. However the course is structured, the lessons around IT issues, the structure of the delivery mechanism, and the impact of online learning on student mindset and learning experience must be carefully thought through and tailored appropriately in order to maintain the effectiveness of the course offering.

The main conclusions from the reflective process behind the writing of this paper are detailed below.

- Mix of online learning and face-to-face 'consolidation' sessions can be a viable vehicle to teach Systems Engineering
- Frequent review of teaching approach and learning experience is vital
- Use of IT can facilitate Systems Engineering learning, but only if tailored to learning needs and used appropriately
- Communication to student of body of approach, and how it evolves, is essential
- Institution of a Student Liaison Committee is really valuable asset in eliciting feedback from students

In terms of future work, it would be useful to apply the ideas learned from the Systems Engineering MSc to other courses to deepen the andragogical knowledge base around online teaching and learning, and further work around understanding student preferences would be valuable to enable more effective and seamless tailoring of delivery mechanisms to enhance the student learning experience.

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