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McKay, A orcid.org/0000-0002-8187-4759, Trowsdale, DB, Carrie, SA orcid.org/0000-0001-5446-4036 et al. (2 more authors) (2022) A Systems Engineering Approach for Blended Learning Design. In: MacCallum, K and Parsons, D, (eds.) Industry Practices, Processes and Techniques Adopted in Education. Springer , pp. 77-100. ISBN 978-981-19-3516-9

https://doi.org/10.1007/978-981-19-3517-6_5

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Chapter title

A systems approach for blended learning design

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Abstract

Blended learning is an increasingly common mechanism for introducing digital learning technologies to student education. However, despite the many technological advances, approaches to support the adoption of such technologies are less well developed. As a result, early adopters tend to be either technologically savvy enthusiasts who are willing to accept the high costs (primarily time) of implementation, or institutions, such as the Open University in the UK, whose missions focus on distance learning. This limits the wider adoption of such technologies by educators who do not have a strategic imperative to use digital learning or the capability (competency and capacity) to adopt it.

This chapter introduces an approach for the design and development of blended learning that builds on ideas behind systems engineering, used in manufacturing industries to manage the design and development of large complex engineering products such as aero-engines and automobiles. The approach will be illustrated through a case study in the design and development of a 7.5 ECTS credit module. Benefits include support for effective multi-disciplinary team working (of teams including academics and learning technologists), a systematic approach to module and asset design, and the ability to accommodate multiple stakeholder requirements in the design process.

Keywords: computer aided learning, systems engineering, learning technologies, module design, digital learning

1 Introduction

Blended learning is widely used to introduce digital learning technologies and their benefits to student education. Learning design in this new [digital] environment is an important issue (Conole, 2013) because the adoption of blended learning in higher education is challenging traditional models of educational design and delivery where individual academics impart knowledge to students. Many uses of innovative methods are reported to improve both students' educational experiences and performance, and the efficiency and effectiveness of delivery and assessment. However, the overarching model of an individual teacher teaching has remained largely unchallenged, with the use of digital technologies focussed on specific learning activities. In essence, the design and delivery of higher education remains a craft-like activity where individual specialists produce bespoke educational artefacts with a view to developing individual students to their fullest potential (Laurillard, Kennedy, Charlton, Wild, & Dimakopoulos, 2018). Achieving similar benefits through a digital platform requires a different approach: one that includes wider, system-level perspectives and contexts in module design and development, in addition to technological innovations.

In this chapter, we introduce an approach that supports the design and development of blended learning modules using a case study module that is 150 study hours or 7.5 ECTS (European Credit Transfer System) credits in size. The module development team was multi-functional including subject specialists, digital learning managers, instructional designers and learning technologists. Challenges in developing such modules include: supporting design iteration; ensuring the expertise of all team members is applied and other expertise is accessed as effectively as possible; minimising waste (primarily of time); ensuring the production quality of digital resources. In addition, there is a need to align the design and development processes that result in blended modules with the stage gated processes used to manage the academic quality of educational programmes. The approach builds on ideas behind systems engineering that are widely used in manufacturing industries to support the realisation of large complex engineered products, such as aero-engines and automobiles, which face similar challenges in coordinating multi-functional teams, assuring design and build quality, and maximising operational effectiveness and efficiency.

We begin, in Section 2, with a review of literature that brings together theories from the design and systems engineering communities with current practice in the design of digital learning materials for higher education. Following this, Section 3 describes the approach introduced in this chapter through an application using the case study as an example. Section 4 provides an evaluation of the approach and Section 5 outlines key learnings and conclusions for wider blended learning design and resource development.

2 Background

This section reviews current practice in the design of digital learning-based initiatives for higher education. We begin, in Section 2.1, with a review of current approaches to learning design and identify key drivers for the introduction of digital learning and wider innovations in student education. Following this, in Section 2.2, we introduce the principles of systems engineering. The approach introduced in Section 3 is based on these systems engineering principles where key drivers were to both ensure that the creativity and capabilities of different team members (including subject specialists, learning managers and technologists) were reflected in the final design, and maximise the benefits of digital learning for students.

2.1 Learning design

The need to appreciate design in the creation of learning at curriculum, module and lesson level is well established. The term 'learning design' is widely used as a concept encapsulating both the procedure by which learning activities are structured, and the output of a design process in the form of a structure or depiction of the learner's journey (Cross & Conole, 2009; Dalziel et al., 2016; Young & Perovic, 2016). Building on this idea, that learning design involves establishing a process for formulating and visualising a learning experience, Laurillard (2012) argues that learning design is a science because it involves reflective practice, observation, and collation of new knowledge to enhance and redesign existing learning artefacts. In adopting the concept of design, practitioners need a logical approach to identify patterns or design solutions that can act as templates, e.g., in the form of a "notational system" (Mor, Craft, & Hernandez-Leo, 2013) or model, for producing learning activities (Laurillard, 2012). The field of learning design attempts to understand the semantics of learning (Young & Perovic, 2016) by establishing a meta-language for pedagogical approaches, frameworks of learning activities, and systems to manage patterns of learning design.

Laurillard's own framework, based on the conversational model she first established in 2002, centres on types of learning and has informed the development of practical methods for designing curricula. For example, her conversational framework underpins the Arena, Blended, Connected (ABC) curriculum design model (Young & Perovic, 2016). The emphasis is on sequencing and compiling 'learning types' to produce a module structure in storyboard form. This is then used for detailed student documentation or to visualise the learning journey (Young & Perovic, 2016). Laurillard's framework also underpins an online design tool with broader application (Laurillard et al., 2018). Other digital learning design process methods, such as Salmon's Carpe Diem approach (Salmon & Wright, 2014), focus on enhancing the technological capabilities of educators by embedding support to create rapid prototypes of existing and new courses. The University of Leicester has integrated a learning activity approach with the Carpe Diem practice to formulate the 7Cs of Learning Design Toolkit (University of Leicester (n.d.); Conole, 2014) which focuses on balancing activity types before moving to the development stage. However, as has been recognised, tools such as the Learning Design Toolkit are "not enough; it must be part of a larger system" (Laurillard et al., 2018). Moreover, the abstraction of learning designs and formulation of patterns is often a challenge in the existing context of Higher Education (Mor et al., 2013) since the characterisation of designs for learning takes time and may not take into account the reality of educational practices in today's institutions. The reflective approach to teaching and learning advocated as part of existing modes of learning design presupposes a model of design in digital learning where an individual academic designs modules. In practice, blended learning is more a socio-technical process (Mor et al., 2013) which involves collaboration between stakeholders who have varying expertise in both technical aspects of digital learning design and delivery, and pedagogic theory.

The need for a systematic approach to learning design, translating requirements into outputs and iterating through a cyclic frame of development, is to some extent met by the widely applied ADDIE (Analysis, Design, Development, Implementation, Evaluation) model. It, like the systems engineering approach outlined in this chapter, allows teams to engage in rapid prototyping based on a situational analysis of the learning context. ADDIE, likewise, contains an evaluative element but, in contrast to the systems engineering approach, this evaluation only takes place once the outputs are delivered to the learner. There is little continuous evaluation offered through rapid iteration of the design and development process. Critics of the ADDIE process highlight that it is front-end loaded with an emphasis on an overly complex design phase (Bates, 2015). Design tasks and the production of design solutions may be allocated to separate teams and there is little further reflection or interaction between separate design teams, meaning that design requirements may not be revisited. The sequences of design and development are also “too pre-determined, linear and inflexible” (Bates, 2015) and thus fail to serve the dynamics of modern digital learning. Most significantly, however, the ADDIE *model* is a misnomer (Morrison, Ross, Morrison, & Kalman, 2013) as it merely serves as a label to describe common phases of design and development. The phases encapsulated in the ADDIE model are vague and this lack of definition means that the process itself is interpreted in multiple ways (ibid).

Learning design has long been of interest for those involved in education and, in recent years, there has been a focus on the term ‘design’. In the Larnaca Declaration on Learning Design, Dalziel et al. (2016) assert that “in many ways, the craft of teaching is still at a relatively amateur stage, and lacks the professionalisation that would come from a richer language for describing the essence of teaching and learning activities.” Systematic team-based tools and methods for module or learning design have already been proposed, developed and tested. Examples include Carpe Diem (Armellini, Salmon, & Hawkridge, 2009), CAIeRO (2018) and Design Develop Implement (Seeto & Vlachopoulos, 2015). Seeto and Vlachopoulos assert that “design has been recognised as one of the key development processes to enhance the learner experience through systematically designed and aligned programmes and units.” These processes seek to develop a method by which groups work together to design and develop learning resources. The relationship between many of these projects can be seen in the JISC Learning Design Family Tree (http://repository.jisc.ac.uk/), where the emphasis lies in the design and development of digital infrastructures to support future innovations in digital and blended learning. In contrast, the emphasis of the approach introduced in this chapter is to support multi-functional teams in developing the innovations themselves.

2.2 An introduction to systems engineering and the ‘vee model’

In this section we introduce the idea of the systems engineering ‘vee model’. The approach introduced in this chapter builds on the idea that systems engineering principles can be usefully applied to learning design. Although blended learning design and development results in largely non-physical products, we argue that there are many common characteristics between engineering product development and learning design.

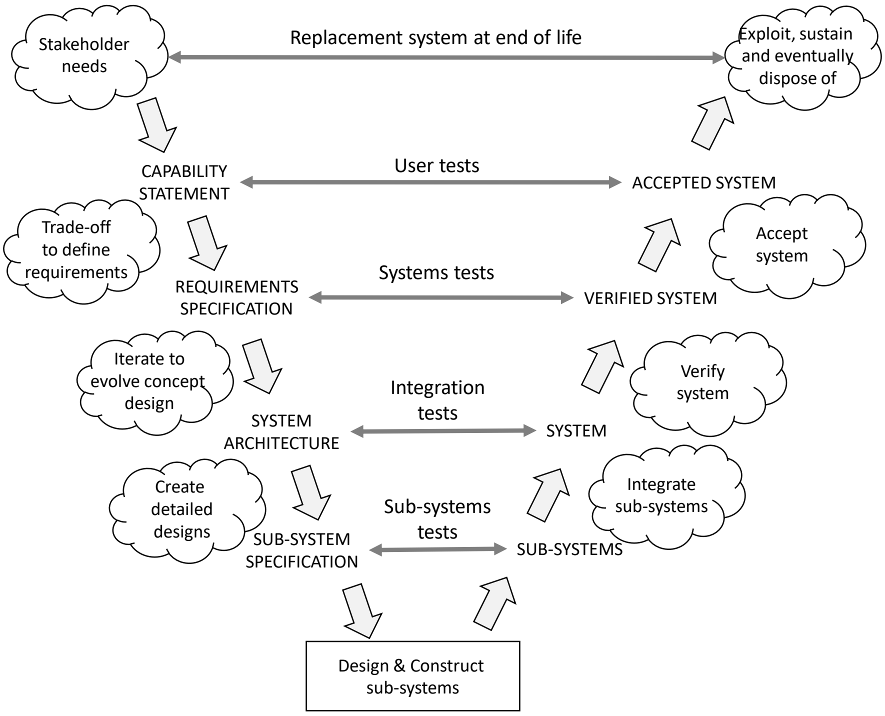

Figure 1: The RAEng Systems Engineering vee model (RAEng, 2007)

In Figure 1, the left-hand side of the vee model relates to design and product functionality, while the right-hand side of the model relates to product realization. Three core processes are embedded in the systems engineering vee model:

(i) the flow down of design requirements (through the left-hand side of the model);
(ii) the flow up of design solutions (through the right-hand side of the model);
(iii) a testing and verification process (between the two sides of the vee model).

It is the testing and verification process which ensures that, as requirements flow down, design requirements for each sub-system are feasible and, as solutions flow up, that they are verified and validated against requirements before being integrated into the wider solution. In this way, the systems engineering approach ensures that design requirements are feasible rather than aspirational at each level, before solutions are developed, and that parts of solutions are functionally adequate before being integrated with other parts of the solution.

Using a bicycle as an example, the systems engineering process begins with an initial capability statement that is used to generate a system architecture, such as the major sub-systems that make up the bicycle, which, in turn, governs the structure of the final product. For example, the high-level capability statement for a bicycle could be “a mode of transport that maximises speed, maintains the user’s fitness and minimises environmental impact”. A number of possible solution principles could meet this need (e.g., scooters, skateboards, etc.) but for the purposes of this chapter we have chosen a bicycle. Once the high-level requirements have been agreed, it is possible to define the sub-systems that form the [bicycle] solution. For example, when regarded as a system, the bicycle has several sub-systems: typically, wheels, steering and brakes, drivers and gears, and frame. Each sub-system can be further decomposed into its sub-systems, each with its own design requirements. For example, the steering and brakes system may be decomposed into two sub-systems, braking and steering; and the steering sub-system may be decomposed into further sub-systems, each with its own requirements, and, ultimately, component parts. For example, the steering sub-system could include a handlebar assembly which is composed of a handlebar, brake lever assembly and gear change assembly. Each of these component parts has its own design requirements, for example, curled handlebars for a road bike and straight for a mountain bike. To create the final solution, component parts are manufactured and tested against their own design requirements. If the tests are successful, then parts are assembled to form assemblies, sub-systems and systems that form the final solution. If tests are unsuccessful then designs and sometimes requirements are reworked before integration continues. In an engineering context, this process ensures the behaviour and reliability of final products which are critical to their operational success.

Our rationale for applying this approach to the design of blended learning modules lay in experiences from early forays into digital learning, by academic staff who acted as early adopters, where significant amounts of time (and so cost) were devoted to developing learning assets and resources that were, overall, very well-received by students. As the use of digital learning became more widespread, and involved more academic and support staff, the institution established stage-gated quality management processes that ensure the quality of digital learning experiences for students but also, and necessarily given its limited availability, restricts access to specialist support. However, while these quality management processes are necessary in any large organisation, they focus on reviews of design definitions and ‘go’/’no go’ decisions rather than facilitating the ways of inter-disciplinary working that support effective and efficient[1] learning design and innovation processes. The approach introduced in this chapter fills this gap.

3 A systems approach applied to blended learning design

The approach introduced in this chapter was developed through application to a series of blended modules culminating in the one used in this chapter. In this section, we introduce the approach by applying it to this module as a design case study. Section 3.1 provides an overview of the case study module followed, in Section 3.2, with an illustration of how the approach supported the design and development of the module down to detailed requirements and specifications of individual assets. Digital learning technologists used these specifications to develop assets while maintaining traceability to design requirements such as learning outcomes.

3.1 Case study module

The module used to validate the approach is part of an online Master’s programme in Engineering Management that was designed from a blank canvas as part of the university’s digital learning strategy. The target students are practising engineers who wish to gain a Master’s degree on a part-time basis while working. The subject matter was on continuous improvement in engineering supply chains and the development team included academics and industry partners, digital learning managers, instructional designers and learning technologists.

The overall structure of the module is described by two formats. Table 1 shows how the module was to be delivered in a tabular format. The first four units had a common structure of three lessons alternated with three activities plus asynchronous and synchronous contact time with tutors. The final two units involved the use of interactive software, so the activities were integrated with the lessons rather than separate, as shown in Table 1. An overall architecture for the module, in the

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[1] In this context, by ‘effective’ we mean creating outputs of the required quality (technically and learner-wise) and by ‘efficient’ we mean achieving this as quickly and cheaply (e.g., measured in staff time used) as possible. This inevitably involves trade-offs but that is the nature of design.

form of the module architecture shown in Table 1 and Figure 2, was developed along with details of teaching methods to be used. The overall architecture of the module was based primarily on the delivery model for the programme, six weeks of learning followed by two weeks for assignments. Figure 2 shows how the lessons and activities can be seen as parts [sub-sub-sub-systems] of sub-sub-systems that we refer to as units. The diagram in Figure 2 illustrates the module as a system that comprises six units, two assignments and a series of in-unit tests. The basic components of the module from an educator's perspective, the lessons, composed of digital assets, and activities, are shown on the right-hand side. It can be seen that the overall module structure, or system, includes components, digital assets, that are drawn together to form lessons, and lessons that are drawn together to form units and so on. A key point, from a systems thinking perspective, is that the parts of each tier in the system decomposition hierarchy have both functional and solution-based

Table 1: Module delivery plan

Unit	Topic	Resource					
1	Introduction to engineering supply chains	Lesson 1	Activity 1	Lesson 2	Activity 2	Lesson 3	Activity 3
2	Continuous improvement methods	Lesson 1	Activity 1	Lesson 2	Activity 2	Lesson 3	Activity 3
3	Product & supply chain mapping	Lesson 1	Activity 1	Lesson 2	Activity 2	Lesson 3	Activity 3
4	Value stream management	Lesson 1	Activity 1	Lesson 2	Activity 2	Lesson 3	Activity 3
5	Introduction to data visualisation tools	Interactive lesson 1		Interactive lesson 2		Interactive lesson 3	
6	Using data analytics tools to analyse engineering supply chains	Interactive lesson 1		Interactive lesson 2		Interactive lesson 3	

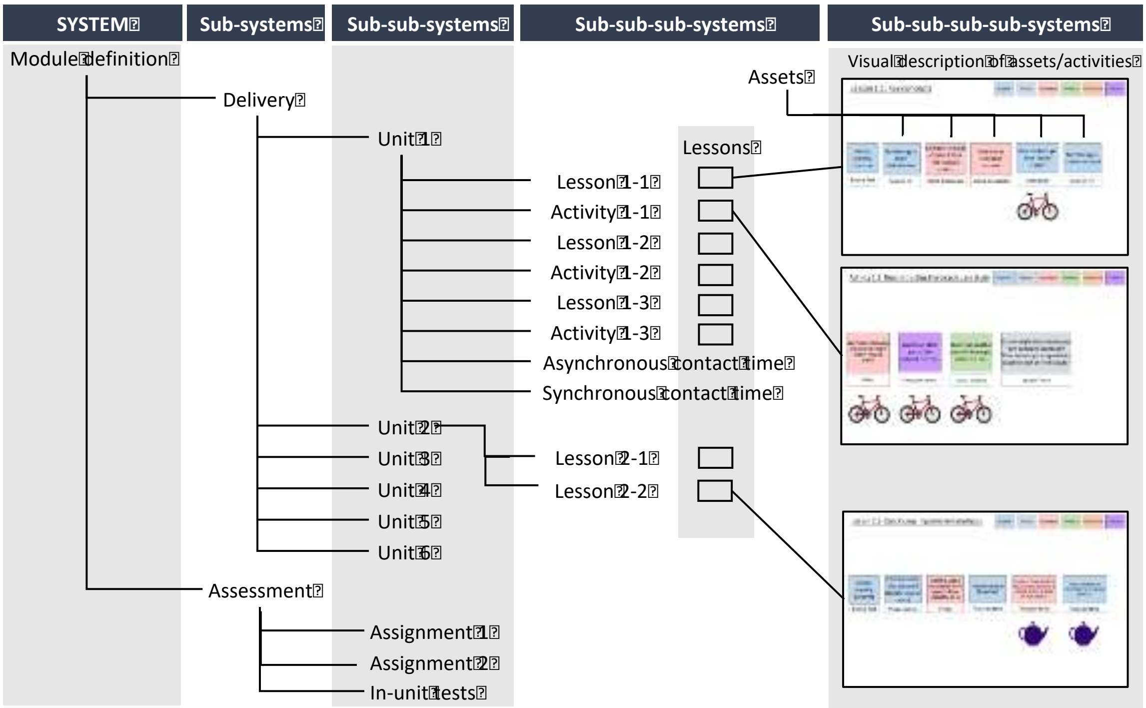


Figure 2: Overall module design from an educator's perspective

definitions. For example, the figure shows units composed of lessons and lessons composed of assets.

3.2 Application of systems engineering principles to the case study module

The decomposition of a system into its parts is a key mechanism for dividing a large design problem into manageable chunks without losing the holistic perspective that is essential for the delivery of complete solutions to users and other stakeholders. A development of the systems engineering vee model in Figure 1, the systems design vee process model (McKay, Baker, Chittenden, & de Pennington, 2018), forms the basis of the approach introduced in this chapter. A version of this vee model, in the form of a repeating pattern, is shown in Figure 3. The model begins with a capability statement and design requirements, and results in a system design. As a whole, the model includes the three key processes that occur in any system design activity:

1 the zig-zagging flow down of design requirements (left to right arrows, required capability to detailed specifications of individual components, solid blue arrows)
2 the flow up of design solutions (right hand side, detail [component definitions] to holistic [whole module design and definition], dashed red arrows)
3 the verification process (dashed double-headed arrows that connect the two sides of the vee)

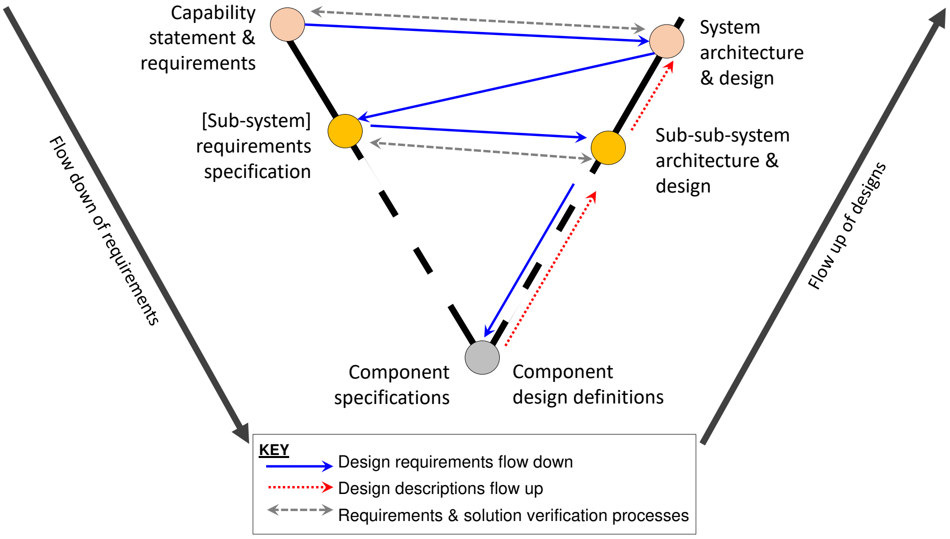


Figure 3: Systems design vee model (adapted from (McKay et al., 2018))

In a learning design context, the left-hand side of the vee captures functional aspects such as learning objectives and outcomes, and the right-hand side of the vee captures design solutions such as module architectures and definitions of digital assets. The zig-zagging between these two sides enables verification of solutions against requirements. In the engineering context this includes physical testing and computational analyses and simulations.

The approach proposed in this chapter is, in essence, a module design process that combines the systems design vee model shown in Figure 3 with the module architecture shown in Figure 2, resulting in the framework provided in Figure 4. In this framework (Figure 4) we have added a black dashed line. Above this dashed line is where traditional quality assurance processes are used to manage the development of the module. In the traditional model, what happens below this line tends to be determined by a subject specialist such as the module leader and perhaps other educators. In the development of digital learning modules, key decisions require input from a team of people. The remainder of this section provides an application of the framework to the case study module.

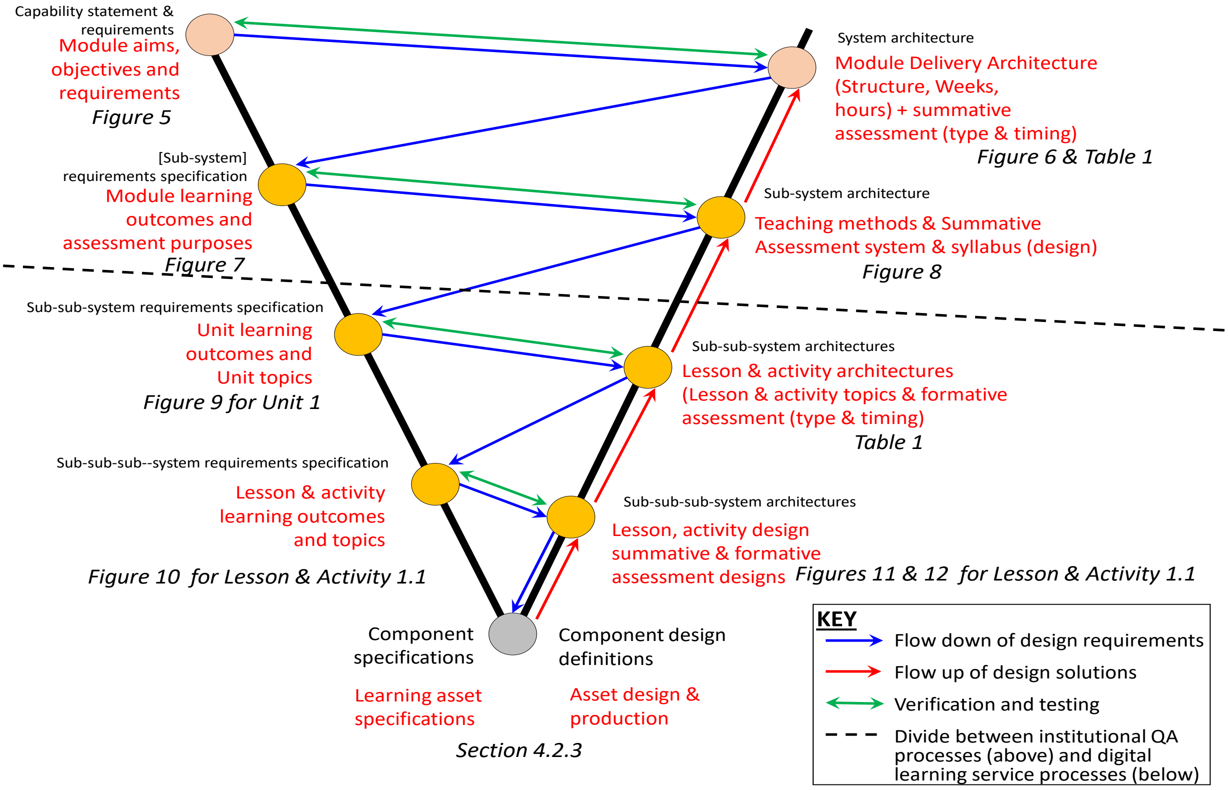


Figure 4: Systems engineering vee applied to the case study

3.2.1 Module definition

In this section we provide information from the documents used to define the module, i.e., those aspects above the dotted line discussed previously, that informed the design of the digital assets and their interrelationships that sit below the dashed line. The module objective (see Table 2) and size (7.5 ECTS) came from the programme design.

Table 2: Case study module objective

Module objective (from module specification): The goal of this module is to equip students with knowledge, methods and tools needed to identify improvement opportunities in engineering supply chains. Students will learn how to apply the six sigma DMAIC process to engineering supply chains and gain experience of the first three stages. For students with an interest in completing a dissertation in the subject area of this module, they will learn key characteristics needed to define projects at the last two stages which could form a dissertation project.

Using the module objective along with wider design requirements such as the need for research-led student education, discussions within the programme and module development team led to the outline syllabus shown in Table 3. These can be seen as the capability statement and the overall system [module] architecture in Figure 4. This information informed the development of the module learning outcomes and assessment purposes (see Table 4) and the teaching methods to be used (see

Table 5). The matrix structure of Table 4 is important because it relates elements of the design solution space, the four assessments, with elements of the design requirements space, the module learning outcomes.

Table 3: Outline syllabus

Outline syllabus (from module specification):
What is an engineering supply chain? *Including why companies work in supply networks; key benefits and challenges; the transition from make to print to design and make networks; network performance; product and supply chain mapping developed through our research.* The role of continuous improvement in engineering supply chains *Including processes such as DMAIC and DMADV (Define, Measure, Analyse, Design, Verify) and ways of identifying, defining and delivering improvement opportunities.* Value stream mapping and the application of digital technologies *Including how to map a value stream, results from current research projects related to computer simulations and data analytics.* Failure modes applied to supply chain systems Introducing students to ways in which supply chain failures occur, current industry practice in addressing these failures and current research activities

Table 4: Learning outcomes and assessment purposes

			Learning outcomes By the end of this module students will be able to:					
			1) identify key characteristics of engineering supply chains associated continuous improvement methods and processes;	2) map out bills of materials for case study products and use these maps to inform the definition of supply chain structures;	3) apply value stream mapping techniques to engineering supply networks and use them to identify metrics for continuous improvement programmes;	4) analyse (using manual and emerging computational methods) engineering supply networks to identify improvement opportunities;	5) describe and identify failure modes that occur in engineering supply chains	6) discuss current industry practices for the improvement and control of engineering supply networks.
Coursework	1500 word project report	60%			✓	✓	✓	✓
	Poster presentation on product and supply chain metrics	30%	✓	✓			✓	
	VLE based MCQs (formative)	0%	✓	✓			✓	
	500 word summary of weekly progress report	10%	✓	✓	✓	✓	✓	✓

Table 5: Teaching methods (from case study module spec)

Delivery type	**Number**	**Length hours**	**Student hours**
On-line Learning	7	1	7
Discussion forum	6	1	6
Independent online learning hours			28

Private study hours	109
Total Contact hours	13
Total hours (100hr per 10 credits)	150

Together, the information in these figures and tables constitutes the core academic content that is used to approve modules through institutional quality assurance procedures. Once approved, in traditional delivery modes, academics are free to develop and deliver the module as they see fit. For blended and digital learning, primarily because of the range of expertise and so number of people involved in developing good quality digital resources, a more systematic approach is needed. As discussed earlier, this is represented in the vee model as the area below the dashed line in Figure 4.

3.2.2 Module development using the vee model

A key feature of the approach introduced in this chapter lies in the transition from a module descriptor, common to all modules, to the learning resources (in our case, digital assets) that were to be used to deliver the module. The systems engineering approach requires the definition of design requirements for all components of the module. These requirements were used to support team-based design decisions and in the evaluation of design solutions. In addition, it was important to separate out the design process, which is collaborative and so benefits from visual methods (e.g., see Figures 5 and 6) that encourage the sharing of ideas, and the definition process which involves documenting the final design for record-keeping and administrative purposes.

In this section, we explain how the systems design vee model in Figure 3 was used in the detailed development of the module, i.e., below the dashed line in Figure 4. To illustrate the approach, we focus in this chapter on the development of assets for a specific unit, the first lesson and its associated activity in the first unit. This unit was chosen because it includes a range of different asset types and, as the first lesson in the module, requires the least subject matter knowledge to explain. With reference to the lower levels of the vee model in Figure 4, the learning outcomes and synopsis for Unit 1 and Lesson & Activity 1.1 are shown in Tables 6 and 7 respectively. The definition of Unit 1 followed the pattern in Table 1 and the design definitions of Lesson and Activity 1.1 are shown in Figures 5 and 6 respectively. A key point to note in Table 6 is the mapping *across* the sides of the vee from learning outcomes to lessons. A similar mapping was not included in the outcomes for lessons and activities because, from attempting to do this for early lessons, we found no value in such detailed definitions. Instead, the subject matter specialists produced synopses for each lesson and, where appropriate, prototypes for each asset including, e.g., preliminary scripts and visuals. Together with the visual descriptions and outcomes, these formed design requirements for the digital assets, both individually and holistically.

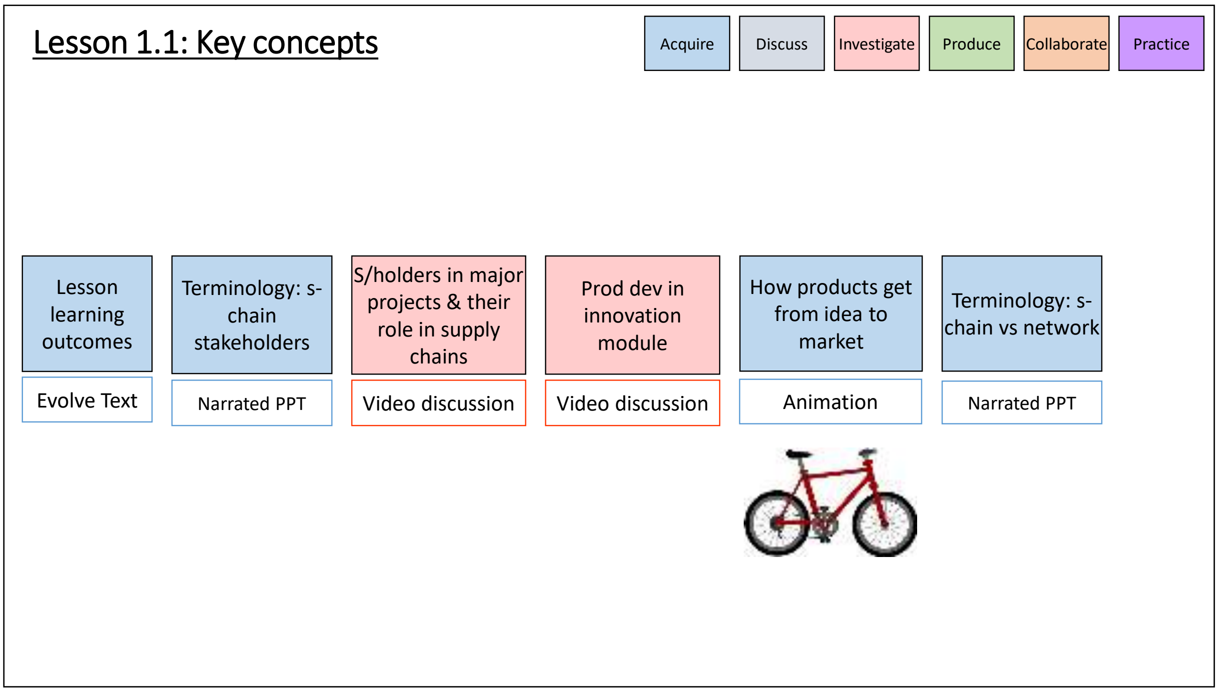
Figure 5 illustrates the visual approach used by the subject specialists to define activities in the lessons so that the digital design team could gain a quick overview of the students' activities and the case studies they were using. For example, in each lesson we focussed on just one case study and, in line with Kolb and others, the mix of activity types (using Young and Perovic's ABC model of six activity descriptors) ensured that the module supported a range of individual learning preferences. The parts of each lesson, the digital assets, were defined using written scripts that were better suited for asset development and were needed by the educators in the production of each asset.

Table 6: Learning outcomes and synopsis of Unit 1

Unit 1: Introduction to engineering supply chains				
Learning outcomes	By the end of this week, students should be able to:	**Lesson 1**	**Lesson 2**	**Lesson 3**
	• Describe the ideas of a supply chain in the contexts of supply networks and product development systems	X	X	
	• Outline key characteristics of make-to-print and design-and-make engineering supply chains in supply network contexts	X		
	• Identify different types of engineering supply chain players and stakeholders	X		
	• Create supply chain maps as collections of interrelated organisations	X		
	• Define requirements of engineering supply chains from a range of stakeholder perspectives		X	
	• Characterise sources of supply chain risk, mitigation strategies and opportunities for future improvement.			X
Synopsis	Students will be introduced to the idea of engineering supply chains: key concepts and characteristics, network performance and the product development process context within which they operate. A bicycle case study will be developed and used through the module. This will be introduced through the week.			

Table 7: Learning outcomes and synopsis of Lesson & Activity 1.1

Lesson 1.1 (Key concepts) & Activity 1.1	
Learning outcomes	By the end of this lesson, students should be able to: • Describe the ideas of a supply chain in the contexts of supply networks and product development systems • Identify different types of engineering supply chain [“make to print” and “design & make”] and stakeholders • Sketch out supply chain maps as collections of interrelated organisations • Summarise key features of the bicycle case study that will be used in the module & could be used to identify other suitable case studies (such as company cases for the assignments)
Synopsis	Introducing students to key concepts & terminology, links to previous modules (stakeholders and innovation) and the bicycle case study



Lesson 1.1: Key concepts

Acquire
Discuss
Investigate
Produce
Collaborate
Practice

Lesson learning outcomes
Evolve Text

Terminology: s-chain stakeholders
Narrated PPT

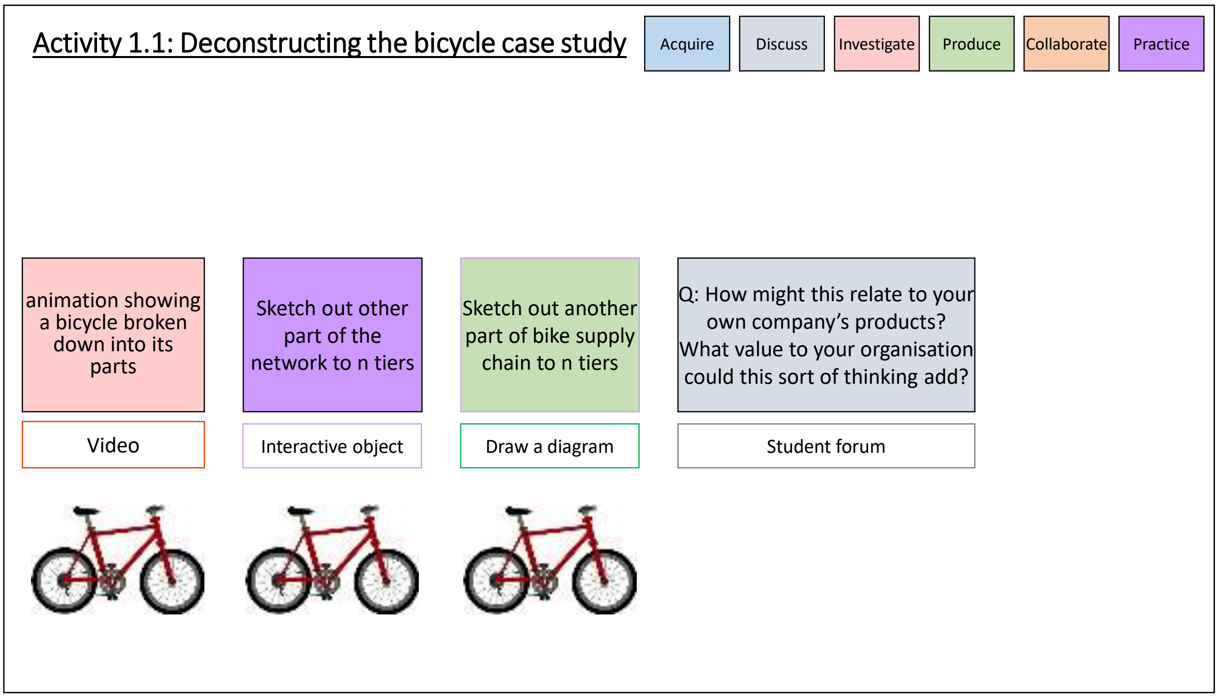
S/holders in major projects & their role in supply chains
Video discussion

Prod dev in innovation module
Video discussion

How products get from idea to market
Animation

Terminology: s-chain vs network
Narrated PPT

Figure 5: The overall design of Lesson 1.1



Activity 1.1: Deconstructing the bicycle case study

Acquire
Discuss
Investigate
Produce
Collaborate
Practice

animation showing a bicycle broken down into its parts
Video

Sketch out other part of the network to n tiers
Interactive object

Sketch out another part of bike supply chain to n tiers
Draw a diagram

Q: How might this relate to your own company's products? What value to your organisation could this sort of thinking add?
Student forum

Figure 6: The overall design of Activity 1.1

3.2.3 Asset design and development

As in the design of the overall module, we used a version of the systems design vee model where, as can be seen in Figure 7, the asset design process was driven from the preliminary scripts and visuals with the outcomes and synopses providing contextual information.

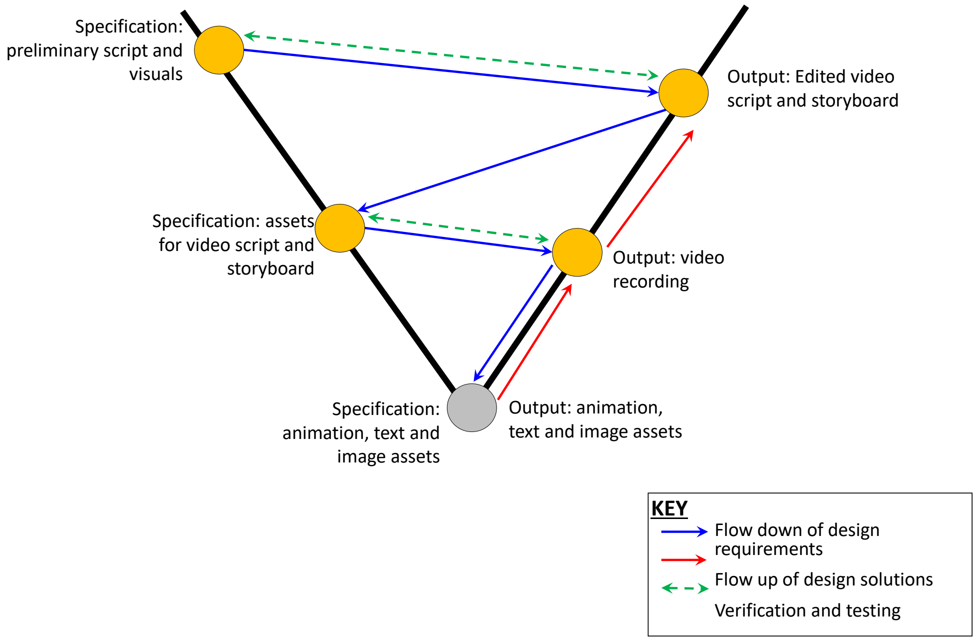
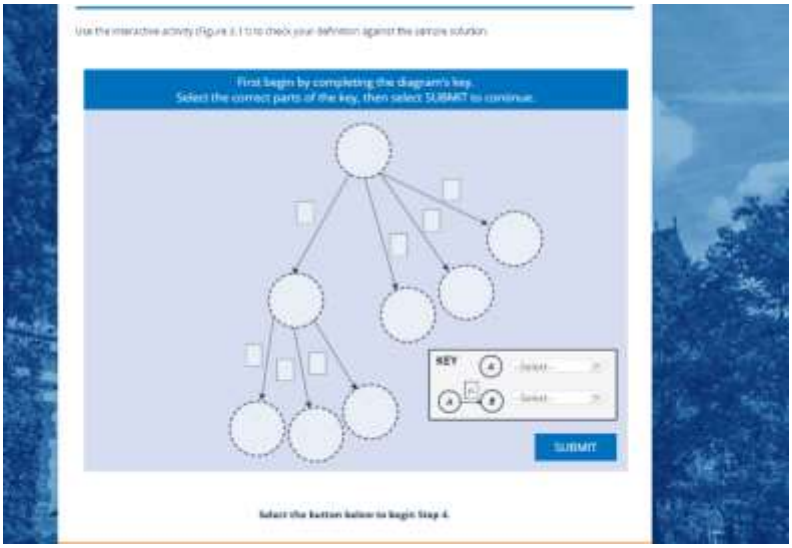


Figure 7: Application of the systems design vee model to the design of digital assets

In the initial design phase, types of learning drawn from Laurillard's conversational framework were used to scaffold the assets within each lesson. This ensured a good balance of learning styles in the content of each lesson. Once the design phase had begun, and individual digital assets were designed and delivered, design requirements were used to validate individual assets. This flexibility meant that, e.g., where a prototype had been developed by a subject matter expert, the development team were not bound by the constraints of the prototype and, instead, could be led by the subject matter in defining the design output. In parallel, the subject matter experts did not need to be concerned with production quality because they were confident that the prototype would not be used as an asset in the final version of the module. In any design and development project, some consideration is given to the most resource-efficient way to produce a design. For example, the production of a video is a far more resource intensive activity (because it involves phases of pre-production, production and post-production) in comparison with a text-based asset that is straight-forward to compile and edit. Moreover, the development team also considered potential reusability and the sustainability of assets. For example, if content was liable to become out of date quickly then a decision was made on whether video was a cost-effective solution. The benefits of the vee were clear in that, in the design phase, uncertainties and the likelihood of changes in the requirements for different parts of the module were considered and decisions made and approved through team design reviews (McKay et al., 2018). While some of this evaluation centred on the traditional measures of time and cost, the key determinant focused on best practice and quality of assets. The example given in Table 8 and Figure 8 evidences the transition from initial scoping of assets (and so learning types) in lesson designs, to the design and then prototyping of the asset itself.

Table 8: Example of an interactive asset design

Lesson outcomes and activity learning outcomes and topics	Students map the structure for another part of a bicycle to the number of tiers. Students use the same bicycle part that they identified in Week 1. The map will be drawn using pencil and chapter (or possibly Word or PowerPoint). Once drawn, students scan/copy their hand drawn work to post in the preceding discussion. *Learning type: PRACTICE Mapping activity*
Learning asset specification	- PowerPoint slides showing solution to the structure diagram for the brake assembly - Checklist: a series of questions for students to use to self-assess their design structures - Further specification: students to point on part of a diagram in response to question prompts - Correct/incorrect feedback: in response to their clicking on the relevant part of the diagram, i.e., in response to question 'is there a key?' students select the key on the diagram.
Asset design and production	See Figure 8



First begin by completing the diagram's key.
Select the correct parts of the key, then select SUBMIT to continue.

Figure 8: Asset design and production: Interactive learning object combining drop-down features and 'drag and drop' for students to complete the design structure diagram. Intermittent feedback provided in response students' answers to questions posed throughout the activity.

3.3 Evaluation

As with any design and development approach or method, it is not possible to establish a direct link between the efficacy of the approach and the quality of its outcome because there are many other factors that could affect the outcome. For example, the capabilities and professionalism of the development team, in terms of academic content, learning design and development, and the implementation of digital learning resources are all critical to overall success. However, given that these were relatively consistent across the different modules developed alongside the one used as our case study, we can provide anecdotal reflections on the impact the approach had on other indicators: namely, the resources needed to develop the module, the elapsed time taken to develop the module, feedback from students and the implementation of change.

With respect to the resources needed and time taken (analogous to cost of development and time to market in industrial product development processes), the module design passed through the

University's quality assurance (QA) processes without any requirements for rework. For this reason, at this stage, it is fair to assert that the design was deemed to be "right first time". As a result, no additional time was needed for rework. Within the University's QA process, the development of assets only begins once a module design has been approved. In comparison with other modules, the time needed for asset development was also significantly lower for the case study module, primarily because there were no requests for significant asset design changes during the asset development process, meaning there was no requirement for rework and no gaps in the digital learning journey were found.

The module was piloted with some of the authors' final year project students (ten campus-based across two years) and then delivered for the first time (to approximately 25 distance-learning students) in Summer 2020. The overall coherence of the module was confirmed in delivery where the module was highly rated by students and no requirements for rework were identified in feedback from students. As the final version of this chapter is being written, the module is about to be delivered for a second time, in Summer 2021. In reviewing the digital assets, the development team learnt that a software tool used in the module would no longer be available to students. A further benefit of the approach introduced in this chapter is now becoming evident in that the consequences of such a change are straight forward to trace through the design of the module, so facilitating effective change management processes.

4 Discussion

In contrast to existing blended learning development processes, such as those reviewed by Khalil & Elkhider (2016), using the systems design vee ensures the verification and evaluation of individual assets *throughout* the design and development process. In addition, it enables a holistic approach where assets are reviewed collectively as entire packages. As a result, higher level module design decisions can be adjusted to improve asset designs and vice versa. This is an important review process because it ensures a consistent and coherent overall product: a blended module. A verification process where each asset was verified against its design requirements was used for two reasons. The first was to verify that the content provided by the subject specialists was suitable for the asset type identified in the course design. Having this verification point allowed for decisions to be made to alter asset types to reflect the most pedagogically appropriate use of the content. In addition, the way in which an individual asset could be updated to reflect future needs was taken into consideration. As a result, this verification step allowed the content to be reviewed in isolation to establish how likely the content may need to be altered or updated should facts and figures be likely to change, more reliable data be likely to appear, or more up-to-date examples be needed. If this risk existed then a decision could be made to produce a less resource intensive asset or to separate the asset into more than one, with the material that is more likely to change in an editable format. This early verification process also allowed for a quicker and more efficient quality approval process for each asset. Again, by verifying them individually, each stakeholder in the process could provide feedback at an early stage to ensure the asset was accurate and to an agreed level of quality, as a round of feedback passed between the asset producers, the instructional designers and the subject matter experts. Each discipline in the development team not only checked the asset against the design requirements, but also against knowledge implicit to them as experts in their individual fields of expertise. For example, asset producers can check for the technical accuracy of the asset, the instructional designers quality assure the digital pedagogy and the subject specialist can check that an asset is factually accurate. This early-stage feedback verified each asset at a point in the development process where inaccuracies could be identified and resolved quickly and without affecting the overall course development.

Secondly, as instructional designers collate assets (text, graphics, interactive learning objects and videos) into lesson packages, the vee model allows the lessons and activities to be verified against their learning outcomes and other design requirements. At this stage other stakeholders in the process, such as digital education and subject specialist peers, can provide feedback that is independent from the development process and so unbiased by it. Verification at this stage in the process again allows for changes to be made to individual assets without having a disruptive effect on the overall development schedule of the module. In the authors' university, the final university quality assurance process takes place above the dotted line in Figure 4 where an external expert reviews the module design as a whole. The feedback from this can then lead to design changes before the module is signed off for production and delivery. In the approval process for the design of the module used as a case study in this chapter, the content was acknowledged as having clear links between the proposed content and the learning outcomes, with a clear learning journey for students from beginning to end of the module. Once the module moved into the development phase, assets were developed and the module built in approximately half the time of comparable modules. In addition to this reduction in time costs, an important benefit of the approach introduced in this chapter lies in the clarity it provides in interfaces between institution-wide, stage-gated, quality assurance processes and module-specific iterative design and development processes.

Stakeholder experiences of using the approach proposed in this chapter have been positive in that it has both reduced perceptions of waste and resulted in a high-quality result. However, further work is be needed to verify these perceived cost savings. The module was piloted with ten Mechanical Engineering Level 3, 4 and 5 (Bachelors, undergraduate Master's and postgraduate Master's respectively) project students with positive results. In contrast to cost savings, as with any design process, it is not possible to draw correlations between student (or other "user") experiences and the process used to develop a design because of the wide range of factors that influence both the design process and student experience. In addition, excellent designs can result from apparently poor design processes, for example, when carried out by a highly competent designer. However, such outcomes are less likely to occur in the design of blended modules where multi-disciplinary teams need to work together and in the context of institutional quality assurance processes. The approach introduced in this chapter is intended for such circumstances and, as in engineering design processes, increases the likelihood of achieving better quality designs by balancing control of the process with the creativity and capabilities of design teams.

Key stakeholders involved in the module for the purposes of this chapter were the module development team and in the remainder of this section we highlight observations from this team. The application of breakdown structures was one the principal benefits of the systems engineering vee approach. The hierarchy shown in Figure 4 facilitated the application of two verification processes and the management of different but overlapping stakeholders. The assessment sub-system involved verification by stakeholders not directly involved in the design and delivery of digital assets, and so this initial separation allowed the development teams to work independently. The decomposition of units into lessons and activities facilitated effective management of the asset design and development process and provided traceability from assets to wider design and learning objectives. The approach provided flexibility to determine the nature of individual digital assets and assign them to team members as each individual component gained more definition. The systems engineering approach recognises the socio-technical dimension of digital learning creation and, unlike conventional models such as ADDIE (Bichelmeyer, 2006), it is a more practical reflection of the way digital learning is developed. Unlike the linear approaches to instructional design, the vee provides multiple entry points for defining requirements and provides a voice to key stakeholders in these processes.

Design iteration occurs at all levels of the vee. At the bottom, during the asset design and development phase, individual assets were verified against design requirements before being integrated into the wider system. The rapid iteration of assets and their validation against requirements took place within the design and development team where, for example, individual animations or images were verified by the development team to assure their accuracy, quality and consistency. This process of verification took place at a smaller scale before the individual assets were combined, for instance, into a video, which was then verified against the learning outcomes specified by the module leader. While in the conventional instructional design model a whole package of learning may only be validated at the end of a prolonged phase of delivery and implementation, the system engineering vee minimises waste in this process by adding further stages of initial verification prior to delivery. The systems engineering approach counterbalances the ADDIE model which has been criticised for its inefficiency (Bichelmeyer, 2006) due to the interdependencies it presupposes between different stages of development in application as both a waterfall or cyclical process (Allen & Sites, 2012). Furthermore, the system design approach allows individual teams and services involved in the creation of digital learning assets to enact their own internal quality assurance and review processes prior to validation through delivery, and by the institution. This is more reflective of the approach common in the design of online learning materials where the delivery of design solutions may be outsourced, and where outputs are subject to controls internal to the asset creator's organisation.

In their paper on motivators and barriers to students' use of e-learning resources, Evenhouse et al. (2020) identify two key factors: relevance and availability. The approach introduced in this chapter helps ensure relevance because digital assets are designed and developed in the wider context of the blended learning experience. More widely, with respect to the seven principles for online learning put forward by Tanis (2020), some are facilitated by approach (e.g., the focus on goals at every level of decomposition ensures that assets have clear objectives which, in turn, ensure that they are purposeful) whereas others (e.g., staff-student engagement) are related to delivery. However, the emphasis on high performance expectations can be seen from the clearly stated course objectives in the syllabus, the structure of online learning resources and their integration with synchronous learning activities; and the mix of activities ensures support for diverse learning styles and student autonomy.

5 Conclusions

The design and development of blended learning modules can be streamlined using the approach introduced in this chapter. In comparison to other approaches, this approach may on first sight seem more intensive, but it is the early verification of each asset that speeds up the further verification steps as the assets are developed and integrated with each other. Without this approach, small changes at a module level can have a significant impact as entire assets have to be redesigned and developed, having a knock-on effect on delivery timescales or, where timescales cannot be altered, the quality of the final module.

Realising the full potential of digital learning, such as that available from blended modes of delivery, requires that it is implemented at scale, i.e., whole modules and programmes, and involves a wider range of educators, some of whom may not be digital learning specialists. The range of expertise needed to implement robust digital learning technology-based solutions means that their development is a team-based activity that utilises a wide variety of expertise and abilities. In contrast to traditional approaches, the development of digital educational products at the scale of modules and programmes requires systematic approaches that support collaborative working within development teams. We argue that the design and delivery of higher education learning is in transition: towards more engineering-like approaches where specialists work in multi-disciplinary teams to produce verified systems that are ready for delivery. Systems engineering processes are widely used in the engineering design and development of large complex products such as aero-engines and automotive products (RAEng, 2007). Key characteristics of systems engineering processes are the separation of the design domain into functional and solution spaces[2], and a design process that zig-zags between these two spaces. The zig-zagging process, which relies on the separation of the functional and solution spaces, provides clarity on the level of detail that is appropriate in a given design description and ensures that customer requirements permeate the entire development process. The approach introduced in this chapter supports design iteration and the zig-zagging process between the functional and solution spaces that characterise all design processes. It provides an effective and efficient means of delivering team-based educational design programmes. In the chapter we have touched on how it interacts with formal quality assurance processes that are used in all UK institutions and our initial experiences have been that separating the [largely visual] learning design process from the [largely text-based] definition processes needed for quality assurance offers real benefits by supporting collaboration and co-creation in the learning design process.

6 Epilogue

The Covid-19 pandemic struck as we were writing this chapter with many institutions announcing a move to online learning at very short notice and with insufficient time and resources to develop entire blended modules. An important feature of the approach in this chapter lies in establishing what constitutes value in blended educational contexts. In the modules where we developed the approach, value was twofold: lower costs of development (measured in terms of staff time) and higher quality of the final digital offering. We benefited from institutional quality assurance processes that require at least eighteen months from initial approval to first delivery of a module. This enabled us to form development teams with time to think, experiment with prototypes and iterate, and resources (such as funding to travel to companies to record interviews and a professional production team) that allowed us to meet our high production quality goals. Responses to the pandemic demand a transformation process where what constitutes value changes. This makes the adoption of systems-based approaches to learning design even more important. We now need to deliver solutions in short timescales and, given the scale of the task, frontline teaching staff are unlikely to have the same access to resources for producing digital assets; we are more likely to be curating assets from third parties and developing our own, inevitably lower production quality, digital assets. However, the student experience will not necessarily be compromised because that depends on the whole systems that underpin new, post-pandemic digital and blended learning activities.

Acknowledgements

The case study module was developed as part of an online Master’s programme in Engineering Management. The development of the approach and so this chapter would have not been possible without the support of the programme leader, Prof Ian Robertson, colleagues in the University’s Digital Learning Team, including Megan Kime and Carol Elston, and the wider programme team.

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[2] Functional spaces where the focus is on the delivery of customer needs and requirements, and solution spaces where solutions are defined and developed

Disclosure statement

The work reported in this chapter did not require ethics approval.

None of the authors have any conflicts of interest in the work reported here.

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