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Evaluating Student Perspectives on Understanding of Complex Systems

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Abstract
Advances in technological detail and sophistication have resulted in more complex products, systems and services which can be more difficult for individuals to conceptualise and understand. This eventuality has potential to increase risks and assumptions in the use, operation, and management over time of such products and therefore presents a growing problem for those who have to plan and undertake such activities. It can thus be seen as important that people are informed as to the possible ramifications of increased complexity, and this presents a challenge to educators in terms of how the notion of ever-increasing complexity can be taught and inculcated. Previous work has considered how this might be achieved, evaluating learner preferences, mechanisms to describe greater complexity and its effects, and teaching strategies which can facilitate that learning and understanding. This paper builds upon the earlier work in the light of having since delivered complex systems course content at masters level. By viewing the situation through the prism of student learning experience and using informal discussion with learners and formal feedback on factors such as comprehension of topic, ability to analyse and evaluate holistically, and capability to apply understanding to real-life business scenarios, this paper assesses areas that students perceived as difficult or challenging to explicate and actualise. This is then placed in the overall context of the course cohort to analyse trends and whether different students experienced problems with the same issues before suggesting a revised andragogical strategy to address issues and improve the student learning experience.

Keywords: Andragogy, Supporting Students, Systems Engineering, Complex Systems

Introduction

Complex Systems are by their very nature difficult to understand. This truism is underlined by various definitions of the term 'complexity': the International Standards Organisation state that complexity can be defined as "the degree to which a system's design or code is difficult to understand because of numerous components or relationships among components" (ISO/IEC, 2009), whilst the Oxford English Dictionary list 'complexity' as being "not easy to analyse or understand" (OED, 2010). Hitchins (2019) posited that "Many people have a view about complexity, but not so many can entirely justify their view", which builds on the above definitions of complexity by suggesting that it is difficult to rationalize and communicate. Previous research has identified factors which increase complexity within a system, as described at table 1 below:

Characteristics	Exacerbating Factors
No. of nodes	What we understand
No. of connections	What we think we understand
Size	What we don't understand
Distribution	Human involvement
Location	Organisation
Level of Detail	Context and Environment

Table 1: Characteristics of Complexity (Barker, 2021a)

A key message from that work is that the extent to which we are able to understand, or not as the case may be, is a critical factor in both characterizing the extent of complexity, and the ability to assimilate and communicate its nature. Various authors have attempted to put forward methods to help explore complexity by unpacking the richness of a problem situation; Peter Checkland developed Soft Systems Methodology partly in response to the need to examine and understand the complexity inherent in organizational problem situations (Checkland, 1999a; 1999b), and this was further adapted and applied by Wilson (1990; 2001). Boulton et al (2015) and Jackson (2019) amongst others have put forward ideas on how to understand, conceptualise, and work with complex systems, whilst Bar-Yam (2005) considered how complex problems could be solved, and Axelrod et al. (2000) advocated the 'harnessing' of complexity in an ever-more multi-faceted organizational world.

At the heart of much of this literature is the accepted reality that complexity is in itself complex, and therefore difficult to rationalize and understand – and that without this, it is difficult to communicate its essence. This is all the more important as physical and organizational situations which we routinely encounter become more and more complex in their nature (Pak et al, 2017; NAO 2020a and 2020b; NAO 2021). As such, it is essential that we are able to educate people in the nature, 'shape' and effects of complexity within systems, and Barker (2021b) considered how this might achieved and put forward an andragogical teaching to achieve it. This considered factors such as the nature of complexity, the learning styles and preferences of students, and the andragogical teaching methods and techniques available to implement such a strategy. This paper builds upon the earlier work described by Barker (2021b) in the light of subsequent delivery of a complex systems course at masters level which utilized the proposed teaching strategy. By reflecting on that experience and attempting to view the situation through the eyes of the students and their learning experience this paper assesses areas that students perceived as difficult or challenging to explicate and actualise. This analysis is then placed in the overall context of the course cohort to analyse trends and whether different students experienced problems with the same issues before suggesting a revised andragogical strategy to address issues and improve the student learning experience.

Andragogical Teaching Strategy and Course Delivery

The proposed teaching strategy considered the nature of complexity (Boulton, 2015; Jackson 2019) and identified potential 'blockers' to teaching. These are listed below in table 2:

<table>
<tr><td>Detail: number of nodes or components, depth of organisational or system development 'layers'</td><td rowspan="4">Stakeholders: number – and variety – of stakeholders, and their
• views,
• intentions,
• Needs, and
• Motivations</td></tr>
<tr><td>Interconnections: Number and variety of links between components</td></tr>
<tr><td>Multi-faceted nature: Multiplicity of competing/conflicting factors needing consideration</td></tr>
<tr><td>Variation and behaviour, especially across time</td></tr>
</table>

Table 2: Challenges to teaching complex engineering concepts (Barker, 2021b)

Consideration was then given to student learning styles and preferences (Honey and Mumford, 1982) and how that might affect the ability of the student to understand the nature of complexity. Students have different learning styles (Barker, 2014), and evidence from literature suggested that different teaching mechanisms would achieve differing outcomes in facilitating learning (Ramsden, 2003) As such, some methods may work for certain students, but not for others (Biggs and Tang, 2007), and given the nature of complexity and complex systems, investigation was conducted into how different andragogical teaching methods may improve the ability of students to comprehend more challenging subject matter. Bligh (1998) contrasted various different teaching methods, whilst others, such as Lohse et al (1994) suggested that the use of more visual methods were a significant aid to better understanding. The work of Bradbury (2016) provoked consideration of the attention span of students, and how that might play into the use of techniques to maximise intake and cognition of information. The conclusion to this analysis was that multiple methods need to be employed interactively to give students the best chance of understanding the subject matter, and this view was supported by the work of Fry et al (2009) who suggested that the use of multiple complimentary teaching methods could enhance the likelihood of better learning. Barker (2021b) concluded in the light of this analysis that attention needed to be focused upon:

- What teaching methods are best suited to informing understanding of multi-faceted, orthogonal subjects involving multiple systems and stakeholders?
- How can these be structured into a coherent pedagogical/andragogical approach?
- How can such an approach be moulded to student expectations and their different learning styles?

Given the intricate nature of complex systems, it was deduced that an iterative approach which broke the subject material down into digestible segments as advocated by Ramsden (2003) would be most likely to succeed (Barker, 2021b), especially if coupled to a clear structure and intent. To which end, Barker (2021b) suggested that the following ideas need to be addressed:

- The "essence" of complexity
- How to recognise complexity
- How to understand the 'severity' of the situation
    - What is the extent of the issue?
- How to describe complexity
    - The degree to which it can be modelled and formalised
- How to communicate the situation
    - How to 'keep tracks' on the spread of complexity

It was considered that the "essence" of complexity, or its intrinsic nature, would be difficult to convey due to factors such as detailed level of abstraction, number of system elements, variety of interconnections, and the propensity of complex systems to evolve and change over time, as identified in table 2 above. This was corroborated by Foster et al (2001) who suggested that complexity can evolve at a faster rate than the knowledge concerning it, which held the possibility of making the subject even more daunting to learners and making the magnitude of the andragogical task facing both teachers and students appear more extensive. An approach to this was to add simplicity and increase meaning by use of pictorial methods to demonstrate the potential creation and subsequent spread of complexity within a system. If combined with the use of real world case studies to demonstrate how this occurred it was thought that learning could be enhanced (Whitman et al, 2002). This could then be reinforced by the use of case study material related to different organisational or industrial domains to place concepts of complexity directly within the contextual knowledge and experience of students, thus making it easier to grasp and relate to. It was believed that tis would make complexity within systems easier for students to recognise and understand in terms of its potential effect, spread and severity.

The use of multi-methodological approaches (Mingers, 2003) could also assist in reducing the difficulty in understanding by exploring the multi-faceted nature of a complex problem situation and providing a more complete holistic understanding of complexity in situ. This view was informed by the work of authors such as Faules (1982) who investigated the use of multi-methods in organisational situations to provide greater understanding.

In addition to the use of pluralistic systems modelling techniques, Barker (2021b) proposed that the use of case studies throughout a module or course had the ability to provide continuity of understanding, offering learners a 'handrail' to guide and build their understanding by developing knowledge incrementally using the same relatable example and construct. By using a combination of these techniques, it was help possible to provide a comprehensive was of describing complexity and testing its extent in a more manageable, semi-formalised approach, which should also help in the communication of the concept. It was also noted that due to the level of course and qualification (UK Government, 2022) in question, the appropriate level of educational quality needed to be maintained. As the course was a level 7 masters degree, this meant in practice that while examples could be demonstrated and discussed in class, there was also the need for students to apply and justify their learning independently, and so it was important that mechanisms be put in place to facilitate this.

In addition to the constraining and enabling factors considered above, it can be noted that there were a number of andragogical challenges to educating students at level 7 which centre around the mental model of the individual student (Barker 2021c). In the case of complexity and complex systems, these might be seen to centre around the individual student's mental model, in that their own experience and knowledge might bias them toward certain conclusions, whilst previous level of learning might facilitate or impede their ability to comprehend the subject matter. Learning preferences (Fry et al, 2009), as mentioned above, could also help or hinder students in their ability to learn, depending on how they reacted to the blend of andragogical techniques employed in the teaching process (Biggs and Tang, 2007).
Having considered these factors, Barker (2021b) proposed the teaching construct below for the level 7 Complex Systems course:

- Live sessions held as 'conversations' rather than formal lectures
- Short follow-on individual exercises to embed understanding
- Provision of worked solutions/model answers
- Q&A/Tutorial sessions to answer queries and repeat material if needed
- Self-paced research exercises to explore particular aspects of relevance
- Longer, group interactive workshops to simulate reality and foster peer-to-peer understanding and learning
- Seek regular feedback from students: session-by-session to ensure understanding and test different ideas
- Consistent 'storyline' through course

It was intended that by employing such a construct, involving the use of a variety of complementary approaches that a holistic, consistent learning experience would be provided that catered for individual learning preferences whilst also supporting the group dynamic within the cohort fostered a comprehensive learning culture. Moreover that this should facilitate sufficient learning and knowledge generation that students should be able to apply, rationalize and justify their understanding independently and therefore meet te level 7 learning criteria of the course.

Student Perceptions on the Learning Experience

Feedback was sought from the students both during and after the initial run of the course. The intention behind this was to gain 'in the moment' responses which would allow teaching staff to gauge the extent to which the andragogical teaching construct was working and to ensure that student learning was progressing as per course intended learning objectives whilst meeting level 7 qualification levels. Immediacy of feedback also allowed to some extent the tailoring of teaching methods to maximise cohort-level learning and to support individual students through iteration of points or additional sessions to ensure comprehension of subject matter either individually or in sub-groups. After-course feedback was also sought to allow students to reflect on their learning experience, consider any elements that they might wish to have reiterated, and to suggest improvements in the light of whole course delivery. This latter method of feedback was intended to facilitate continuous development of the course teaching strategy, and to identify improvements that would better facilitate student learning.

Feedback during Course Delivery

During the delivery of the course, teaching staff frequently paused delivery f material to ask if students had any questions or required any clarifications. At the end of each teaching session, a Q&A was held to allow students to ask questions or request iteration of information, and informal tutor sessions were also offered to garner opinion on the learning process as it happened. The key responses from this means of seeking feedback are listed below:

- students found the technical and mathematical areas of content to be very difficult to understand
- Complexity theory was difficult to grasp
- Structured approach was good for understanding fundamentals of complexity
- Multiple examples helped
- Group workshops increased understanding

Several of the students expressed the view that the more theoretical elements of subject matter such as complexity theory were more difficult to understand, and those unused to recent academic study were particularly strong in their views on this matter. Although some students were happy with detailed theory, the majority expressed a preference for a more practically structured learning experience in which models and techniques cold be applied to defined case studies to build up their understanding of complexity and its affect upon systems. Most of the students provided positive feedback on the structure of the module, stating that an approach to incrementally increase understanding had helped build their familiarity with concepts, and the shorter exercises had helped considerably in this endeavour. All of the students found the interactive nature of the teaching strategy to be beneficial, especially the provision of multiple examples and worked solutions whilst the longer group workshop was found to provide contextual understanding whilst providing a collegiate multi-stakeholder ‘support network’ of shard ideas.

Feedback received subsequently to Course Delivery

At the end of the course, a wrap up session was held to allow the students to ask questions about the course material, clarify the intent and deliverables of the summative assessment, and to provide initial feedback whilst the learning experience was fresh in the memory. Experience from teaching on other modules and courses suggests that some students are uncomfortable when asked to provide feedback publicly, so students were given chance to either/or complete an anonymous feedback online questionnaire at a later date, or to email feedback to the course leader. Feedback given during the course wrap up session reinforced the earlier view that the course structure and teaching construct had successfully facilitated learning but that the subject of complexity was difficult to understand, whilst the interactive nature of the teaching had helped understanding and given the students increased confidence in their knowledge and learning experience. The mix of individual exercises leading to group workshops also received praise for facilitating learning and fostering a good learning environment. The main points of feedback received via the anonymous questionnaire and/or via email were as follows:

- The nature of complexity was difficult to understand
- The subject matter was very challenging
- It was good following lectures, but hard once there was no direct guidance on context
- It was difficult to apply learning independently
- Following the text of books directly would help

Some of the feedback received from students subsequently to the module was similar to that received during its delivery. In particular, the students reflected that complexity as a subject matter was difficult to understand, and that while complexity could be understood locally within a system, it was much more difficult to understand holistically. Some students identified the subject as being challenging as concept, particularly due to the evolutionary nature of complexity and its emergent property of changing the nature, state and behaviour of the system under consideration. Other comments related to learning preferences, in that whilst students generally enjoyed the lectures, case studies and worked examples, some experienced difficulty in characterising complexity in a system without guidance and independently making sense of a situation and justifying their findings. Finally, a limited number of students expressed a preference for book-based learning that precisely followed the text of supporting course material. This might have been due to a lack of experience contextually, or a lack of previous academic study on more advanced subject matter.

Reflections and Response from Teaching Staff

Upon commencement of course delivery it very quickly became clear that there was a divergence of experience and academic ability amongst the cohort. Some students possessed academic qualifications at levels only slightly below that at which the course was being delivered, whilst others lacked in qualifications but had a vast amount of industrial domain experience. The effect was that whilst some students experienced difficulty in adapting to the academic style and level at which the course was pitched, others were less able to relate the subject matter to real world examples. It was found that broadly, the students fell into the following categorization:

- Those who were unable to deal with the intricacy and nuance of the subject matter
- Those who were able to follow the detail during lectures, but were then unable to conceptualise and apply it in context independently
- A relatively small number who were able to fully grasp the concept and evaluate associated issues independently

This caused some difficulty in that level 7 qualifications require students to be able to conceptualise arguments, rationalise ways forward and justify their reasoning; those able to do this more readily grasped the concept, but some students struggled to grasp the more detailed theoretical concepts and therefore had difficulty in reaching expected levels of attainment. Other students coped well whilst being provided with an iterative step-by-step approach along wit worked examples and case studies but were less able to work independently where required to do so. This necessitated reiteration of some of the material, and inclusion of a more structured approach than was intended. This resulted in a focus on teaching essential concepts in a greater depth, which was in some ways more akin to training than education. Moreover, the emergent property of this was that some moe advanced concepts could not be covered due to lack of time which required restructuring of the teaching construct in something approaching real time and meant that additional effort had to be spent to ensure that the integrity of the course as a level 7 qualification could be maintained. This was achieved through breaking down tasks into smaller independent work sessions, assessed formatively and backed by worked examples and extensive feedback to provide the students with confidence in their understanding, and then followed by a more open, reflective, piece of summative assessment than had originally been intended.

Other issues encountered were that because of the divergence in knowledge and qualifications amongst the cohort, some students need more tutoring than others, so effort had to be expended to ensure that the learning experience did not become disjointed at cohort-level. The preference of some students for step-by-step instruction led to some of the cohort progressing more quickly than others, such that in some cases normal and 'extended' tasks needed to be set to facilitate learning preferences, styles, and rates of progress. In addition, some students expressed a preference for learning structured against accompanying texts. It is questionable whether such an idea is compatible with level 7 qualifications, and again this necessitated additional work to facilitate the learning of some members of the cohort.

Revising and Evolving the Andragogical Teaching Construct

In considering the feedback from the students and the reflections of the teaching staff, it is considered that although the course construct was broadly successful, there is the potential to evolve it in a number of ways. Firstly, it is considered that the nature of complexity and complex systems understanding might lend itself to a multiple-tiered teaching approach that splits the topic into foundation- and practitioner-level courses, wit the former providing learning on key concepts of complexity and demonstrating how it takes affect and propagates itself along with case studies and worked examples, whilst the latter is pitched as a level 7 qualification that allows students to debate and relate more advanced concepts to their domain experience and conduct independent evaluation as to how complexity can be managed and contained appropriately within a systemic context. In a similar way, if the subject matter is being delivered as a module of a long-form course, then it might be appropriate to move the module to the latter end of the course construct, which would allow students to build knowledge and experience before tackling a more advanced topic such as complex systems. In this way, pre-requisites in terms of experience or knowledge from earlier modules could be used to smooth and improve the learning experience. It is also noted that in a long-form course context, a complex systems module could be paired with an alternative module to allow a student to avoid the study of complexity should they be too uncomfortable with such a prospect.

In addition to this, the delivery of the course construct could be adapted to 'sign-post' more potentially difficult material allowing students to have additional time to prepare for it and ask any questions that they deem relevant ahead of time. It is also possible to develop a wider range of cases studies to form a library from which material can be taken to apply to any industrial domain considered relevant, therefore increasing the chance of students being able to better relate the subject matter to their individual knowledge and experience.

Conclusions

In conclusion feedback from students reinforced the view that complexity is in itself inherently complex, especially due to its propensity to evolve, mutate, and therefore alter the behavioural and structural properties of the systemic entity in which it is present. The feedback received on both the course construct and andragogical teaching strategy employed to deliver it was broadly positive, suggesting hat a mixture of interactive discussion-based lectures coupled to a developing case study used as the backbone to the learning experience, plentiful worked examples and a mixture of short individual learning tasks and longer group workshops provided a mechanism well-suited to facilitating the learning experience and fostering an engaging, collegiate, learning environment.
The feedback also showed that some students adapt to learning and embracing difficult topics more readily than others. Individual learning styles play an important part in this, but the experience of individual students also plays a significant part in their ability to understand and contextualise more challenging subject material, as does their academic preparedness and familiarity. Reflections from the teaching staff reveal that the cohort who attended the course contained a diverse range of academic qualifications and industrial domain experience, and this in cases led to the necessity of teaching at individual student- rather than at cohort level which proved disruptive and required changes to the original andragogical construct. As a cohort there was unanimity of views that the group workshop significantly helped group understanding, and the students did appear to work well as a unit. The outcome was that at a cohort level the course intended learning outcomes were met, albeit at the cost of the teaching staff investing additional effort to ensure that all students reached broadly the same level of understanding before the course could progress to the workshop activities. The additional time required to achieve this did result in changes to the original course construct, and a conclusion from the initial running of the course would be that cohorts with a wide range of abilities make advanced topics much more difficult to teach. In terms of future work, as a result of delivering an initial course on complex systems and reflecting on hat experience in preparation for this paper, the author believes that the following should be undertaken:

- Continue practical and theoretical research into how to characterise and describe complexity, and how best it can be taught in order to refine and evolve the most suitable andragogical teaching strategy for the teaching of complexity and complex systems

- Experiment with different teaching styles and constructs to attempt to discern the most appropriate balance of teaching techniques and how they can be mapped to individual and potentially cohort learning styles and preferences

- Work with individual students to better understand learning preferences when faced with the task of understanding and making sense of challenging subject matter so as to facilitate the continuous development of the student learning experience whilst also informing the other aspects of future work stated above

A further conclusion upon reflection is that the course needs to be run on a number of occasions to accurately gauge the most appropriate teaching strategy, to understand more completely the level at which the delivery of challenging subject material can or should be pitched, and to test whether the feedback from this cohort is typical of all students or is due to the diverse nature of learners in this particular cohort.

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