Tools and techniques to stimulate higher order thinking in online learning

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***Abstract*—The Covid-19 pandemic has created a range of challenges as teaching and learning moved from face-to-face to totally online delivery. Many learning providers were obliged to move to fully online learning from March 2020 with some adopting hybrid approaches in line with government and health advice. Many university programmes were rapidly redesigned to be delivered online but this is not just a matter of providing resources in digital format. While there is no agreed definition of higher order thinking (HOT) it is generally understood that HOT elevates thinking to levels beyond restating the facts. HOT involves understanding of the knowledge, inference from them, connections to other facts and concepts, categorisation, manipulation of the knowledge and finally, reconstructing them into new or novel ways to provide solutions to unique problems. We discuss the challenges of achieving HOT within the online environment but also the import of providing opportunities for students to engage fully with the entire range of learning levels. In this paper we consider HOT within the context of a pyramid learning structure with lower order thinking at the base and higher order thinking dominating the apex; building from remembering to understanding, applying, analysing, evaluating to creating. We provide a review of our experiences of experimentation with a range of different learning activities such as discussions, quizzes and assignments delivered on a VLE (Canvas) for an undergraduate cohort studying Computing and Information Technology related course of degree study. We review the impact of different curriculum items and educational activities to promote HOT on student experience and the achievement of learning outcomes.**

We reflect on how students learn via online content delivery and we propose how the learning experience can be enhanced to promote higher categories of cognitive thinking. We demonstrate how a pyramid model of curriculum activities facilitates the learner scaling from knowledge to the more challenging skills of creation and how this effective learning environment facilitates higher order thinking practice. We propose practical examples of the application of a pyramid learning structure within e-learning environments to deepen student learning, student access and engagement with leading to successful students' workplace experience in the future.

Keywords—technologies in education, e-learning, higher order thinking

I. Introduction

In a world which has unlimited quantity of information instantly available in digital form, the need for students to develop the skills to critically analyse and evaluate this information is paramount. Increasingly, employers are seeking employees who can think, reason and innovate to create new solutions to ever more complex problems. In order to prepare students of Higher Education for the challenging world of work in the 21st century, a cornerstone pedagogic goal is to create opportunities for students to engage in higher order thinking at all stages in their academic journey.

It is generally accepted that Bloom's Taxonomy [1] has provided one of the most advanced models to illustrate the levels of learning from Lower Order Thinking Skills (LOTS) to the acquisition and demonstration of Higher Order Thinking skills (HOTS). This classification was later revised by Anderson and colleagues into the "Revised Bloom's Taxonomy" [2]. In this model the nouns are replaced by verbs to focus on the cognitive process. Additionally, the process of "creating" (which involves synthesis) is elevated to the highest taxa reflecting the authors' views that the skills required to bring elements together to form a new structure or form are of the highest order (Fig. 1).

Bloom's Taxonomy	Revised Blooms Taxonomy
Higher Order Thinking Skills (HOTS)	
Evaluation	Creating
Synthesis	Evaluation
Analysis	Analysing
Application	Applying
Comprehension	Understanding
Knowledge	Remembering
Lower Order Thinking Skills (LOTS)	

Fig. 1. Bloom's Taxonomy and the Revised Bloom's Taxonomy

While Bloom's Taxonomy provided the first systematic classification of the processes of thinking within a learning context, the revised version with its taxonomy table provides a "clear, concise, visual representation" and tool to assess engagement with the different level of thinking skills within the curricula's learning and assessment activities [3]. In the process of designing curricula the pedagogic aim is to ensure that all levels of thinking skills will be activated and assessed. It is widely accepted that the design of activities which activate the higher order skills prove to be more challenging, however the Bloom's Taxonomy provides a roadmap to achieve the progressive climb from lower order thinking skills to higher order thinking skills.

The point at which lower order thinking moves into higher order thinking is often debated. In the scientific field activities within the curricula focus more on problem solving and creating, whereas critical analysis is considered to be more reflective of higher order thinking within the humanities. Lewis and Smith proposed the following definition: "Higher order thinking occurs when a person takes new information and information stored in memory and interrelates and/or rearranges and extends this information to achieve a purpose or find possible answers in perplexing situations" [4]. This

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definition encompasses both the science and humanities foci and resides within the highest taxa domain, "Creating" in the revised Bloom's Taxonomy.

Whether Bloom's Taxonomy or the newer Revised Bloom's taxonomy are employed in curriculum design, a scaffold is provided in which to plan the learning and teaching activities around the educational goals. By aligning the activities to this hierarchical structure, a coherent programme of activities can be effectively designed to develop and encourage thinking skills through the six levels within the cognitive domain. Progress from the LOTS to HOTS levels may not always be strictly linear, for example evaluation make take place after a process of creation but gaps within learning can be easily identified by aligning learning with the levels in Bloom's Taxonomy.

II. Activating Cognitive Learning Domain

Various techniques have been reported in literature to activate the higher orders of a learner's cognitive domain which are concerned with understanding, analysis, synthesis and evaluation [5]. Many of these techniques rely on integration of technology to support learning, and there is broad recognition that this can be done in different ways, but ideally should lead to a transformation of the learning task [6].

In this section we present the results and experiences of different educational activities – quizzes, scenarios and creative tasks – targeting the higher-order cognitive skills and offered to the students as a part of online module delivery for the undergraduate Level 2 Computing and Information Technology (CIT) cohort, studying Systems Administration and Support Module.

At the start of 2020-2021 academic year all UG and PG programmes taught at the School of Electronics, Electrical Engineering and Computer Science in Queen's University Belfast were rapidly redesigned to be taught fully online using Microsoft (MS) Teams and the Virtual Learning Environment (VLE), Canvas. For CIT Level 2 students studying Systems Administration and Support module, both platforms have been fully integrated into module delivery including the following e-learning features embedded into online learning:

- Pre-recorded lectures and live lecture recordings;
- Online lecture notes, labs and practice challenges delivered through and available on VLE Canvas;
- Formative assessments in the form of online quizzes containing multiple choice, open-response and scenario questions with unlimited number of attempts. These are designed for self-directed learning purposes and to provide immediate feedback on student knowledge and skills.
- Summative assessments delivered on Canvas, including marking, instructor's comments and feedback;
- Support and guidance via Microsoft (MS) Teams Chat / Polls and Canvas Discussion Forums to give students an opportunity to ask more detailed questions relating to the topics covered. This has provided a platform increase their engagement with other students and the instructor while working / learning from home environment.

Traditional curricular components, such as lecture notes and practical guidelines focus on the lower categories of Bloom's taxonomy, i.e. remembering and understanding. Whereas higher categories – analysis, evaluation, creation – became the focus for the educational activities. With that, each level of cognitive thinking is important and built on the last, i.e. the lowest level can't be excluded from the picture but needs to be used as a base to develop the higher orders of thinking. This is also an iterative process in which a student will return to the earlier steps after starting the process in a higher order. Although there is no shortcut to the top of Bloom's taxonomy, the online technologies are considered to be helpful to get learners to the top in more efficient way. Use of technologies to stimulate higher orders of thinking helps to prepare students for a more successful working future as higher order thinking is highly sought by employers [7, 8].

Bloom's taxonomy has been applied in the e-learning environment for CIT Level 2 students to promote analysis, evaluating and creating using online quizzes, creative assignments including scenario questions and discussion forums (Fig. 2).

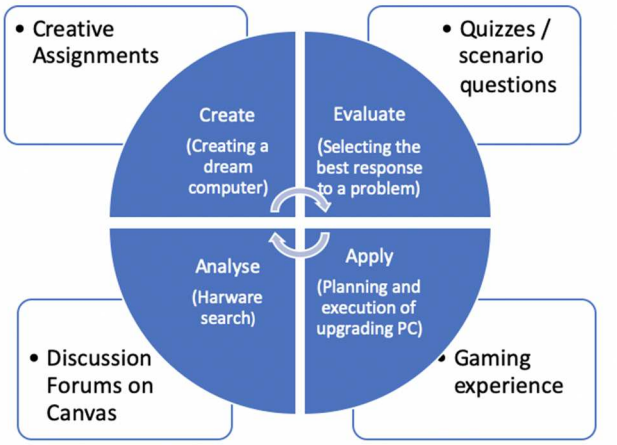

Fig. 2. Inducing higher orders of thinking: e-learning environment for Systems Administration and Support module (CIT course)

III. Online Quizzes and Scenario Questions

The quizzes were designed in several formats to cover all aspects of Bloom's taxonomy, starting with remembering and understanding and moving on to higher orders of thinking. The quizzes provide a vehicle to enhance the learning experience as well as provide an assessment experience [9]:

- Match questions in which the students are asked to match phrases and terms to evaluate broad understanding of the subject.
- "Fill in the blank" questions to challenge their critical thinking in terms of analysis of the material within the covered topics.
- Multiple-response and multiple-choice scenario questions to make students think critically, evaluate and analyse instead of just testing the information, e.g. "Select the best response to the situation considering what you've learned about…" or "Select any consequences there might be of the action considering the covered techniques…", etc. Fig. 3 shows an example of multiple-response question with the

breakdown of correct / incorrect answers (source: VLE Canvas, Systems Administration and Support module)

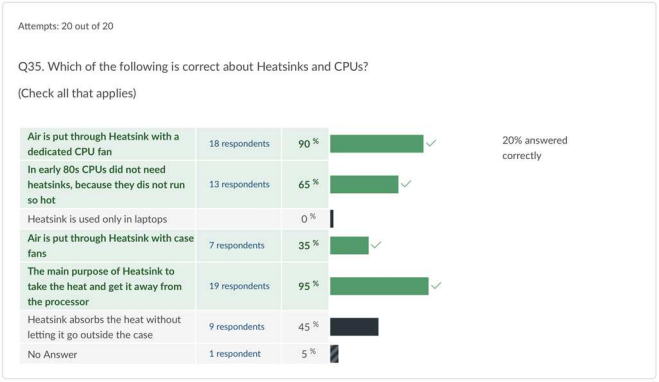

Fig. 3. Stimulating higher orders of thinking: multiple-response question

Such a mix of questions, challenging different aspects of understanding the material and critical thinking, provides an opportunity for students to become more aware of their strengths and of the areas in need of development within the subject as well as updating them on their progress.

IV. Creative Assignments

Creative assignments are considered to be another form of educational activity which requires higher order thinking and interestingly is most enjoyable by the students. These kinds of educational activities require thinking to reach levels of creation, evaluation and analysis. Open-response scenario questions to evaluate problem-solving skills has become an integral part of a creative assignment. Students were requested to conduct their own research in a creative way for the following tasks:

Exercise 1. Office PC. You have a budget of £500 to build a computer for general office work. It will be connected to the corporate network. We already have a display we are happy with (so the budget is just for the main computer itself). Compile a full list of components and costings for such a system, including any particular decisions you've made (maybe for cost reasons) and why. Once you have specified this machine fully also have a look at the big PC retailers (PC World, eBuyer, Dell, etc.) – how does your system match up? Is it cheaper to build or buy?

Exercise 2. Home Dream PC. Having made a lot of money consulting on the office PCs in exercise one you now have £3000 to spend yourself on your dream computer for home (to fulfil your ideal use case, be that gaming, coding, virtual reality, etc). Note though this time: (1) You have no displays so this must be included in the spec; (2) You don't have to build everything from scratch – is there an off-the-shelf computer that matches (maybe with some upgrades) what you need?

Exercise 3. Upgrade from Off-the-Shelf. A customer of yours has bought this computer from a provider (link provided). However they: (1) Find it very slow to start up; (2) Can't play 3D games on it; (3) Regularly get an "out of memory" error when video editing. What upgrades are possible? What would you recommend? Detail each upgrade along with the supplier (including URL) and the rationale behind your choice and belief it is compatible. Note: you may need to go beyond the retailer website to find the detailed specifications of the machine."

The creative research assignment was very well received by the class, the student feedback on the assignment appears to be extremely positive:

Feedback (Freya T., ICT student): "I found this practical very helpful in understanding the different prices and components for building and purchasing computer parts. I enjoyed researching different computing website and comparing prices to ensure I stayed within the budget. I got to witness the massive range of items and kits that are available and the potential complexity in finding stuff that all fits together. I especially enjoyed the third exercise where we got to upgrade a computer already chosen for us as I got to research potential future problems that may arise in the computer and how I would go about fixing them."

Feedback (Anthony M., ICT student): "It served as an enjoyable way to demonstrate my learning through this module and to put the things we have learned into practice. The PC part picker website was very useful through its built-in compatibility selection and clear layout with price and specification visible. The most challenging exercise was the first, as I had to build an office PC within a limited budget. However, using mid-range specification products such as the Intel i5 processor and 8GB of DDR4 RAM I was able to produce a powerful enough PC for the required function. The dream PC task was the most enjoyable. I was able to get carried away selecting the highest possible specification products for an ultra-modern, high performance computer. For exercise three the built-in compatibility feature helped a lot. It enabled me to select compatible parts at the cheapest possible price that would hopefully solve all issues that the computer currently suffers from."

V. Discussion Forums on VLE Canvas

In addition to quizzes and creative assignments, higher-order thinking has also been stimulated by Discussion forums on VLE Canvas. Discussion forums were offered to the students regularly after the relevant topic was covered during online lecture classes. Students were offered to perform search on hardware parts of their own PCs / devices and answer the questions: "What RAM you got? What's your CPU? What's your storage set up?, etc.", that students found really useful and entertaining. Students devised their own solutions through the process of discussion (Fig. 4). Average number of forum participants was 32 students out of 44 in the class (72%).

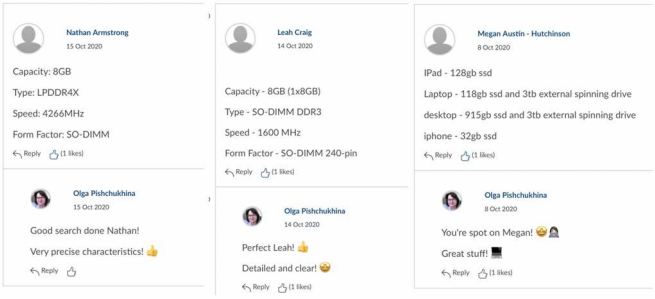

Fig. 4. Stimulating higher orders of thinking: Discussion forum on hardware search

On-line discussion forums help to communicate with students in an innovative way, enhancing their cognitive thinking and guiding learners to the top of Bloom's pyramid.

End-of-term feedback suggests that through the use of formative Canvas quizzes and access to online resources

student learning has been enhanced and resulted in a positive student experience. Students appreciated the online quizzes and creative assignments, interactive training activities during live sessions and level of engagement with the class. Fig. 5 represents some student responses (25 students) as a part of mid-term anonymous feedback poll that demonstrate student satisfaction with scenario quizzes and creative assignments.

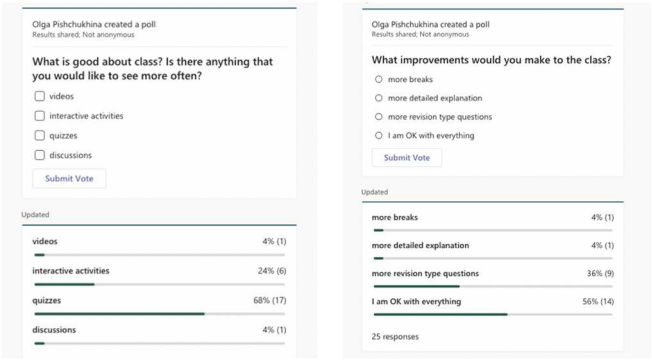

Fig. 5. Systems Administrations and Support module: student feedback

Student feedback on use of quizzes and creative assignments including scenario questions with a focus on preparing for the assessments, has been overwhelmingly positive. Some student feedback on Systems Administration and Support module is represented below:

"Module material followed by quizzes and scenarios are very useful, help make the module enjoyable and less stressful. Practical tasks are included with the learning material which enforces learning as you progress through the studies. Learning about hardware and the windows server was very interesting and made me consider it as an option for future work and study".

The experience suggests that the students have engaged fully with the entire range of learning levels, including higher cognitive thinking: understanding, analysis, synthesis and evaluation.

VI. Gaming Experience for Successful Learning

Gaming experience has become another form of reaching HOT. The provision of distance practical classes for Systems Administration and Support module has been considered as the biggest challenge to be addressed due to the nature of the practical classes, where students are required to be present physically. Previously activities involved experimenting in building their own machines, fitting together and upgrading the separate components of the computer.

Before the Covid-19 pandemic all tutorial sessions contained a number of practical sessions which are an important part of the module and designed to ensure the specific learning outcomes are achieved, such as:

- Identify, understand, and troubleshoot all major PC components;
- Understand the process, planning, and execution of upgrading PC hardware.

The face-to-face teaching had to be excluded due to the COVID-19 pandemic which made it impossible to continue with the previous laboratory tutorial sessions for the Systems Administration and Support module. This involved students being taught how to choose, upgrade, assemble and disassemble computer parts, etc. within the laboratory setting. Students still needed to gain practical experience to build building their confidence in running hardware without being impacted on by a lack of practical material. The challenge presented by the current pandemic was how best to provide the best learning experience without the physical laboratory setting.

PC Building Simulator game on Steam was considered to be the best option to resolve this problem, providing distance practical classes to help students to learn hardware components and upgrading operations [10]. Using PC Building Simulator, the students can learn to diagnose, fix and build PCs. With real-world licensed components and comprehensive hardware and software simulation, including brand new inventory and customisable cables, they are able to plan and build their ultimate PCs being supported by a step-by-step guide. Given that PC Building Simulator's official partners are Intel, Nvidia, MSI, Antec, ASUS, Arctic, Deep Cool, Gigabyte, Be Quiet, Raijintec, Zotak, Patriot, it is understood that the students would get invaluable industry and commercial insights while creating with unlimited real-world brand-new parts in free mode (Fig. 6).

In September 2020 Connected Learning Innovation funding was applied to in order to buy 44 PC Building Simulator licences for the class. The Connected Learning Innovation fund was available from the Engineering and Physical Sciences Faculty to support staff who wished to innovate in digital and distance-based education. PC Building Simulator licenses were requested for the students in order to provide a realistic alternative to the regular lab experience. Due to the situation which unfolded in 2020, the physical hardware labs which were always a key part of previous years before pandemic were no longer available. The application was successful, and Faculty funded licenses of PC Building Simulator for the CIT class of 44 students. PC Building Simulator was installed in the computer laboratory machines and actively used by the students remotely.

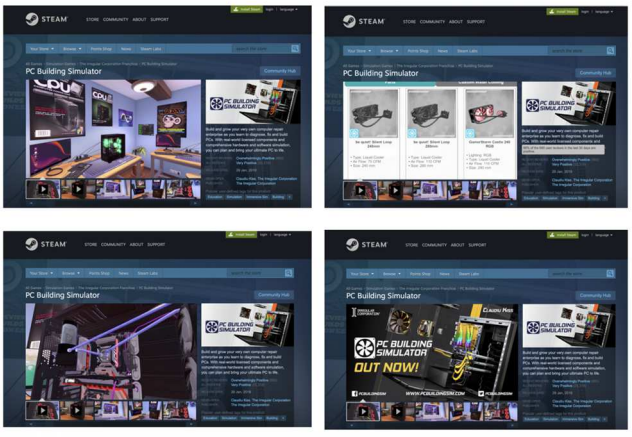

Fig. 6. Stimulating higher orders of thinking: PC Building Simulator projects

This provided a digital experience of learning on how to diagnose, fix and build PCs. Students have provided feedback that they have benefitted significantly by this approach and the experience has been very positive: *"I enjoyed the game - PC Building Simulator. I have found it very beneficial in terms of creating my own machine and understanding some of basics on which computer hardware operate. There were many processes and terms that I had seen before but never took the time to figure out what they meant or how they work, but I feel*

now that I have a greater understanding. Fantastic experience!"

Fig. 7 represent mid-term student feedback on whether playing PC Building game has reached their cognitive thinking level. It appeared that 38 out of 44 students in the class – 86% of the class – have recognised that PC Building Simulator could become a valuable addition to physical hardware labs in the long run, and also responded very positively on the statement that PC Building Simulator has enhanced their hardware skills and facilitated higher order thinking practice, i.e. applying knowledge, analysing and evaluating (Statement 1 on the graph). 42 out of 44 students in the class – 95% of the class – agreed that playing the game has stimulated more challenging skills of creation and reconstructed knowledge into new or novel ways to provide solutions to unique problems in hardware components (Statement 2 on the graph).

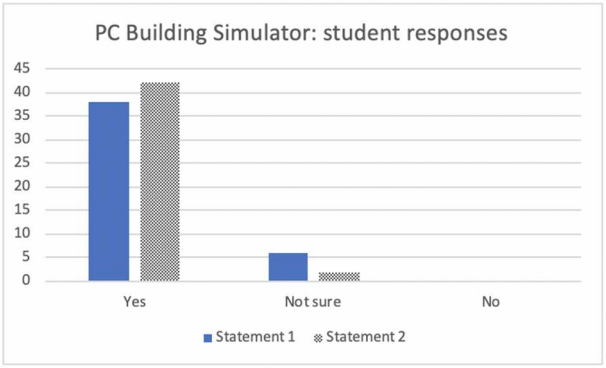

Fig. 7. PC Building game and HOT: student responses

The above suggests, that gaming software, as such, has played its crucial role in activating higher-order thinking while delivering the module online, being an alternative to face-to-face teaching, and helped to achieve the desired learning outcomes.

VII. Software Engineering Final Year Project

In the final year double weighted module Software Engineering Project, students form into teams and work on a problem to design and develop a software engineered solution. Team meetings and regular "Stand-ups" would have normally taken place within the Computer Science Building, either formally within allocated appointment slots or informally as teams worked in the laboratory setting. As learning moved totally online this presented a challenge to ensure that effective collaboration and higher order thinking skills could continue to be developed in this new situation. In response to the challenge of providing an alternative digital learning experience for the students during a significant period of lockdown the academic staff looked to the literature to guide the process.

Churches proposed a Digital Taxonomy which was an update on the Bloom's Revised taxonomy to "account for the new behaviours, actions and learning opportunities emerging as technology advances and becomes more ubiquitous" [11]. In addition to the hierarchical model of learning in Bloom's Taxonomy, Churches overlays collaboration as an essential activity that occurs at all levels of the taxonomy. Lee argues that "collaboration, interaction, and the learning community are the driving forces to sustain motivation for learning and even the paths to learning" [12].

The challenge presented itself as to how to ensure effective collaboration and community learning in the face of a rapid move to online learning. In order to maximise team working effectiveness, online collaborative and project management tools were used to set up digital spaces in which team members could work together on their team project, while being physically situated in their own homes. Microsoft (MS) Teams was used as the primary module hub with each team allocated a private channel. These channels were only accessible by the team members and relevant academic staff. All meetings were held within these channels and the chat function was used to provide a platform for synchronous and asynchronous communication between team members and with project supervisors. Meetings were recorded (if full agreement was obtained) and this provided team members opportunities to review discussions after the event. If a team member could not attend due to illness, poor connection and so on, the meeting would still be available to review and consider. Students were encouraged to make full use of a range of MS Teams integrated software apps such as, but not limited to, Miro (for the ideation process), Trello or Jira for project management, Kanban board for tracking tasks, OneNote for recording minutes etc. An example of a project MS Teams channel tabs is shown in Fig. 8.

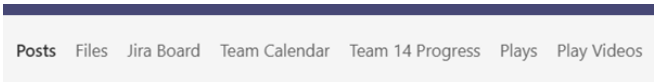

Fig. 8. Example of Team App usage in Microsoft Teams Channel

Lectures providing guidance on relevant topics were delivered and recorded through the main Module Team channel. The VLE (Canvas) was the main point of reference for Module Resources and for broadcasting messages to all students enrolled on the module. Many of the activities were planned to run synchronously, such as scheduled lectures, team meetings, project supervision, paired programming but alongside this, records were taken and resources available 24/7. This provided the additional effect of providing an opportunity to team progress asynchronously and as a record of both individual and group involvement and contribution.

While the tools were provided to facilitate learning, as Lee stated "using an online tool does not guarantee meaningful interactions that can induce higher-order thinking skills and ultimately lead to learning" [12]. One of the important elements in developing higher order thinking is teaching presence or teacher social presence in which the teaching staff in some form in this digital space. The teaching staff is required to demonstrate an effective role facilitating and directing the learning process [13]. To this end, the instructor scheduled bookable appointments (synchronous) to discuss and review the progress as demonstrated by the activities and materials within the shared collaboration. Asynchronous presence was also provided through chat and ad-hoc team stand-ups. The latter of these, while potentially disruptive to the facilitator, provided opportunities for queries to be discussed or resolved in a timely manner supporting an agile development approach. Students reported that the informal "catch ups were invaluable and really helped to motivate the project". In spite of the added challenge of working collaboratively only in a digital space the students worked in teams to effectively develop and creating innovative solutions to challenging problems.

VIII. Conclusion

With the fast paced and continuous adaptation of the Computing and Information Technology sector it is not possible to teach every solution as many of the problems that our students will face have not yet been discovered. Therefore, the aim of addressing higher-order thinking is to equip students with the tools needed to tackle real-world problems, the knowledge of how to use these skills and guide their creativity to overcome previously unseen problems [14]. Our teaching interest primarily has focused on such techniques to target the learners' higher-order cognitive skills thereby helping students to move through the learning model levels from remembering to understanding, applying, analysing, evaluating and finally creating. In this study we have considered the tools and techniques that can be used to support learners to develop HOTS and particularly within a fully online environment. Discussions, quizzes and creative assignments have been embedded in the learning environment within the Computing and Information Technology disciplines and have been shown to provide valuable online support to the students. Quizzes provided an opportunity to scaffold questions, thereby raising the level of thinking as students progressed through the content. Feedback from students was overwhelming positive and evidence of complex thinking approaches was provided in the outputs from the wide range of tasks set for the students. Creative assignments provided challenges which required critical thinking to solve unseen problems. These were well received by students and responses demonstrated a range of HOTS being applied by the students. Discussion forums were also introduced to provide both, an opportunity to think critically around topics under discussion, but also a much-needed opportunity for students to engage with and learn from each other as well as from the lecturer. When laboratory practical classes were prevented, a gaming experience was provided to simulate the laboratory experience. The gaming challenge proved to be very popular and a high number of the students were in favour of maintaining this form of learning experience within the module, even if learning was to resume on-site in the future. These activities provided an opportunity for the application, analysis, evaluation and creation of a solution to an unseen or novel problem. An online learning community platform with associated project management tools was provided as an effective means to encourage and maintain effective collaboration in team-based project in a fully remote environment. Evidence provided by the outputs and activity in the online platform showed high levels of collaboration across teams. Students demonstrated effective higher order thinking as they worked towards the creation of their new software engineering product supported by collaboration across the entire project lifecycle.

All of the above approaches are flexible in meeting new learning patterns, i.e. the pattern of online learning due to the impact of the Covid-19 pandemic. We introduced a range of innovative approaches and e-learning technologies to activate the cognitive learning domain, so that students can enhance logic and problem-solving skills and their application across Computing and Information Technology disciplines. Future work will include the search for other online or digital solutions which aim to support all levels of learning, but particularly those which will enhance the critical skills associated with higher order thinking.

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