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The Virtual Classroom: A New Cyber Physical System

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***Abstract*—The current educational, societal, and technological changes bring online teaching to the forefront. This impacts both the way tutors teach and students learn. This also transforms how all these stakeholders interact with each others. In order to effectively address all these challenges, we consider the virtual classroom as a cyber physical system (CPS) which integrates computational and physical processes as well as aids humans' interactions through many modalities. Furthermore, we propose new interaction patterns to get a maximal interactive teaching and learning online experience, while saving network resources and reducing interface complexity.**

***Keywords*—Man-Machine Systems; Interface Patterns; Cyber Physical Systems; Systems Engineering; Development Life Cycle; Multimedia Softwares; Virtual Classroom; Online Learning; Distance Learning; e-Learning; m-Learning.**

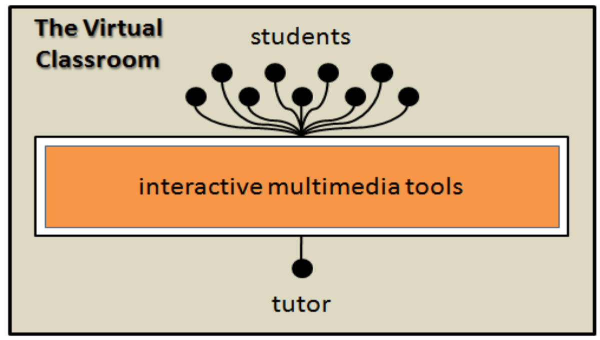

Fig. 1. The Virtual classroom overview.

I. Introduction

Nowadays, with the growing digitalization of the Society, multimedia softwares and information technologies (IT), including artificial intelligence (AI) and machine learning (ML) [1], become pervasive from human-centered applications such as in-flight entertainment (IFE) systems [2] to industrial applications such as robotic systems [3].

In the sector of Higher Education (HE), technologies such as virtual learning environments (VLE) are now part of the everyday life. A virtual learning environment (VLE) [4], or online learning platform, is a software that creates a digital classroom by blending several multimedia supports, such as slideshows, text, audio, video, animation, simulation, and quizzes [5], allowing online learning such as e-learning and m-learning [6]. Usually, the VLE is combined with a management information system (MIS) into a wider learning management system (LMS), in which all aspects of a module (i.e. delivering, tracking and managing the module) are handled through a consistent user interface throughout the institution [7]. Hence, the VLE tracks data about attendance, time on task, and student progress. Tutors can post announcements, mark assignments, check on course activity, read and respond to forum questions. Students can submit their work, participate in class discussions, and take quizzes [8].

However, in situations such as the Covid-19 pandemic [9], further technological and pedagogical challenges [10], [11] need to be addressed in order to transfer the whole in-class teaching to the virtual classroom (Fig. 1).

Actually, this move from traditional or hybrid teaching [12] to fully online teaching and learning (T&L) [13] implies a change in the traditional T&L space towards new socially distanced cyber environments which should be transparent, enabling, stimulating, associative, cognitively integrated and socially integrated [14].

It also impacts on the design, delivery, and assessment of a module, since the module should be aligned from intended learning outcomes to assessment tasks and criteria, while providing a blended mode of T&L delivery, with both online and distance learning, creating thus multimodal ways of learning [13]. Moreover, it results in the fact that alternative assessments should be put in place to replace some of the traditional assignments, and further mechanisms to provide feedback should be set [13], in order to ensure learning outcomes can be met.

Other aspects of such change include virtual attendance management, students and staff's well-being when working online [15] on the connected campus as well as data security and integrity when using widely IT technologies [16].

Whereas some online technologies were successfully applied to remote work [17], virtual work collaboration [18], or continuing professional development (CPD) [19], their introduction in HE has led to a mixed situation where increased student-drop-out rates were observed in the case of massive open online courses (MOOCs) [20]. The identified issues of such distance learning were student anonymity, the solitude of the learning experience, and the lack of interaction with peers and with tutors [21].

Thence, the cornerstone aspect of online teaching is the appropriate human interactivity, in order to deliver a quality T&L experience [22].

Moreover, online learning is cybernetic, i.e. the learning is dependent of the use of communication technologies and feedback smart tools [23]. Therefore, the appropriate selection and interconnection of the IT tools and models to connect, communicate, and collaborate in the cyberspace, whatever between the tutor and the students or in-between the students, is crucial [24].

For this purpose, some studies have proposed to enhance educational technologies with the cloud [25], artificial intelligence (AI) [26], virtual reality (VR) [27], or augmented reality (AR) [28]. Other works have suggested to use open learner models (OLM) to adjust the teaching content/pace to the learner's style/progress [29] or to adopt context-aware learning models to adapt the module content to a wider variety of connected IT devices such as personal computers, tablets, interactive whiteboards, or even multi-touch tabletops in the classrooms [6]. On the other hand, some attempts have been made to introduce further digital interaction into a classroom, e.g. through social media [12] or through multi-user virtual environments (MUVEs) for computer-supported collaborative learning (CSCL) [30]. However, these solutions do not offer a complete interactive online T&L experience.

Hence, in this paper, we present at first a life cycle to build a virtual classroom, which contains not only various multimedia supports, such as slides, text, embedded videos, etc., incorporated into a VLE, but also interconnected to the users (i.e. students and tutor) through IT technologies such as screencasting, webcasting, etc. Since it is important to consider the pedagogy beyond the technologies [31], we propose then interactive patterns which act as intelligent backbone helping to create a fully interactive virtual classroom, with both synchronous and asynchronous capabilities, leading to a new cyber-physical system (CPS) for education.

It is worth noting that the proposed life cycle and designed patterns aim to guide the development of the virtual classroom in order to address the module learning objectives and support students' engagement. Thence, the developed virtual classroom becomes an interactive medium to aid students to achieve the learning outcomes, while fostering community.

Besides, a module's virtual classroom should meet both e-learning and m-learning needs, optimize both tutor and students' experience, and bolster both online learning and distance learning by providing a balance between synchronous and asynchronous T&L activities; the planned asynchronous communication tools allowing additional processing time for students and widening inclusivity.

On the other hand, the proposed virtual-classroom patterns impart clear rules of interactions and provide solutions to specific aspects of the online learning as well as remote assessment challenges.

Therefore, the contribution of this paper is twofold. On one hand, we propose a systematic approach to develop the virtual classroom and evaluate available e-learning technologies and, on the other hand, we elaborate patterns to interconnect the multimedia tools in order to build a quality virtual classroom for interactive and remote computer science education.

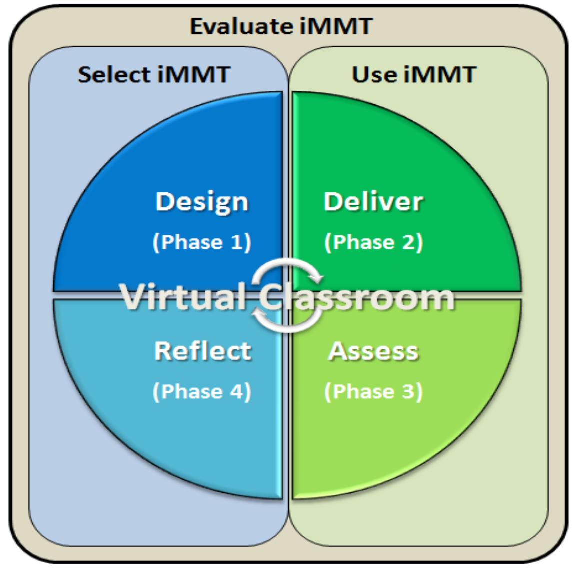

Fig. 2. Virtual classroom development life-cycle.

The paper is structured as follows. In Section II, we present our process to develop the virtual classroom in context of computing and engineering teaching and learning, while in Section III, we apply this process to online module design and development and we report the results and patterns for the successful deployment of our virtual classroom in several case studies. Conclusions are drawn up in Section IV.

II. Building The Virtual Classroom

In this section, we explain how to build a virtual classroom embedding multimedia softwares to aid computing education. The proposed life cycle for the virtual classroom development is described in Section II-A, while its CPS architecture layers and possible IT technologies are presented in Sections II-B and II-C, respectively.

A. The Life-cycle

The virtual classroom development life-cycle consists of four phases, as follows:

- Phase 1 (P1): the design [13] of the virtual-classroom module, based on the module learning outcomes;
- Phase 2 (P2): the delivery [13] of the virtual-classroom module, based on appropriate interaction patterns;
- Phase 3 (P3): the assessment [32] of the students' assignments, aligned on the module learning outcomes and following adapted assessment patterns;
- Phase 4 (P4): the reflection [33] on the virtual-classroom module, including students' engagement and results [32].

Hence, the virtual classroom is developed in P1 and deployed in P2 and P3. On the other hand, the interactive multimedia tools (iMMTs) of the corresponding CPS system are evaluated through the entire cycle. Indeed, the IT technologies are selected in P1, considering criteria such as availability, accessibility, etc., as explained in Sections II-B and II-C. Then, the iMMTs are used in P2 and P3, according to patterns aiding to achieve the learning objectives and buttress the pedagogical approach, as presented in Section III in context of computing modules. Reflections about iMMT efficiency to address the T&L objectives as well as overall usability are made in P4.

B. The Layers

The virtual classroom is a type of technology enhanced learning (TEL) we defined by three technological layers (Fig. 3) from bottom to top, as follows:

- Layer 1 (L1): the multimedia softwares for slideshows, text, animation [5], embedded videos, and quizzes [34];
- Layer 2 (L2): the VLE, usually enhanced with MIS [35];
- Layer 3 (L3): the screencasting and web conferencing applications [36].

These three layers constitute the new educational, core cyber-physical system. Other T&L tools could be accessed outside the main CPS, which serves then as T&L hub, e.g. at L1 for the reading material available in the digital library (DL); at L2 for a specialized software and corresponding Integrated Development Environment (IDE); or at L3 for extended reality (XR) tools such as virtual reality/augmented reality/mixed reality environments. Indeed, computer science education requires the use of specialized softwares which should be available through valid student licenses, freewares, or emulators. Further IT software components may also be integrated into the module delivery, but not directly incorporated within the core CPS platform. This includes mailbox, social media, attendance register, mark register, etc.

It is worth noting that many systems have been called virtual classroom in the past [7], but do not contain the CPS layer 3. This top layer consists of video broadcasting/web conferencing softwares which enable students and tutors to communicate with each other via webcam, microphone, and real-time chatting via the same application. Students are also able to whiteboard and screencast when given rights by the tutor who sets permission levels for microphone rights, chat, and video/audio recordings [37]. Moreover, smart tools allow participants to raise hands, answer polls, or take tests [11].

C. The Tools

To aid interactive education of computing and engineering, the virtual classroom should consider a variety of IT tools and IT equipments for its core CPS, as follows:

- audio and video (e.g. screencasting, webcasting);
- specialized softwares (e.g. local licenses, freewares, emulators, virtualization);
- VLE, MIS, LMS;
- quizzes and polls;
- slides, text documents, embedded videos (e.g. screencasting, webcasting);
- computers, tablets, and mobile devices.

Examples of available IT technologies for the corresponding e-learning supports are presented in Table I.

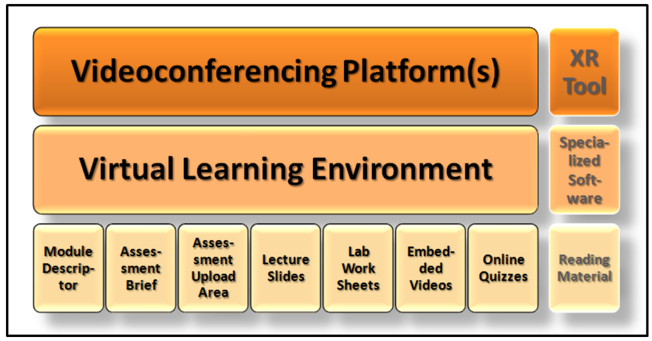

Fig. 3. Virtual classroom technological layers.
Virtual classroom technological layers.

TABLE I
EXAMPLES OF IT TECHNOLOGIES FOR E-LEARNING SUPPORT

e-Learning Support	IT Technologies
Slides	Powerpoint, LaTeX
Documents	Adobe pdf, Microsoft docx
Quizzes	Moodle Quizz, Blackboard Test
Videos	YouTube, Medial
VLE	Moodle, Blackboard
Webcasts	Microsoft Teams, WebEx, Zoom, GoToMeeting

To enhance collaborative and social e-learning/m-learning experience [38], further online tools such as blogs (e.g. Slack, Jabber), collaborative tools (e.g. Google Drive, OneDrive), collaborative code management (e.g. GitHub, Bitbucket), ePortfolios (e.g. Mahara), or social media (e.g. Facebook, Twitter) which might be available on the connected campus/smart campus [39], could be linked to the main educational CPS.

Besides, tutor's feedback could be provided through a wide range of IT softwares which are integrated or linked to the core CPS, depending on the required immediacy and available bandwidth [9], as follows:

- live video/audio conference (for high bandwidth, high immediacy);
- recorded videos (for high bandwidth, low immediacy);
- chat and/or comments in collaborative documents (for low bandwidth, high immediacy);
- emails (for low bandwidth, medium immediacy).

III. RESULTS AND DISCUSSION

To demonstrate the usage of our virtual classroom development life cycle, we investigate several computing modules in order to move them fully online, as explained in Sections III-A-. As described in Section III-C, patterns have been then established to aid the interconnection of IT technologies to build adapted virtual classrooms for these modules.

A. The Case Studies

We have studied five modules which have been delivered for UK undergraduate computer science education. These computer science modules adopt a project-based pedagogical approach. They are delivered by a single tutor, and the students are incoming students, continuing students, or finalists. Four modules were designed for full-time students and one module for part-time students. The size of groups can vary from 7 to 70 students (i.e. n*students), and in case of large cohort, the students could be split in several smaller groups, leading to several runs.

The modules have online content developed and incorporated in the VLE and delivered by the tutor in a synchronous mode through the core CPS. The modules have also additional asynchronous material such as videos and quizzes for students to further reflect on the module content.

B. The Requirements

To help students to achieve their learning outcomes, each virtual classroom has to be a social and transparent space for online interactions and collaboration.

For this purpose, the goal was to design patterns to interconnect the students with their tutor(s), their peers, and the core knowledge; to help them to acquire the required technical skills and graduate attributes as per set learning outcomes (LO); and to guide them to build their personal development portfolio (PDP).

To meet these quality requirements for delivery [40] and for assessment [32], we observed that the patterns have to mitigate the group size as well as the type (e.g. coursework, exam, etc.) and the mode (individual/group) of the assessments. Hence, a one-size-fits-all approach is not flexible enough to accommodate the different needs of the different modules [13]. On the other hand, in order to reduce tutor's orchestration overload [36] and avoid students' over-stimulation [41], creating patterns which act as an intelligent backbone and clearly set the rules of interactions for the different types of situations occurring in the different modules appears to be an efficient way to handle the synchronous/asynchronous delivery and assessment within the virtual classrooms, as presented in Section III-C.

C. The Patterns

Patterns for both teaching delivery and assessment have emerged from the study, and they can be applied to customize the virtual classroom building in order to optimize the user experience, i.e. both tutor's teaching experience and student's learning experience, as explained below.

On one hand, 6 patterns for teaching delivery (Fig. 4) using the core educational CPS have been established, as follows:

(a) lecture (synchronous): in case of n*students-to-1tutor, the delivery of the lecture content follows the webinar style, i.e. students' microphones and cameras are off to spare on the bandwidth; the synchronous interaction being through the CPS video delivery of the tutor and the CPS chat in between students and tutor (Fig. 4(a));
(b) lab work (synchronous): in case of 1student-to-1tutor, the delivery of the lab is a mix of asynchronous and synchronous interactions through the CPS; the student working on the lab exercises and the tutor staying in the virtual classroom, available on video call (Fig. 4(b));
(c) workshop (synchronous): in case of n*students-to-1tutor, the workshop is delivered in a meeting style with the group of students interacting each other via all the CPS video/audio/chat channels, while the tutor joining the students' group meeting to discuss together (Fig. 4(c));
(d) tutorial (synchronous): in case of 1student-to-1tutor, the T&L follows the meeting style where both tutor and student connect to the virtual classroom CPS with all channels on for the time of the meeting (Fig. 4(d));
(e) seminar (synchronous): in case of n*students-to-1tutor, the module content is delivered through the CPS in a meeting style with both tutor's and students' microphones and cameras on and chat available (Fig. 4(e));
(f) home work (asynchronous): in case of 1 student doing distance learning, s/he accesses CPS L2 and L1 channels (e.g. to read slides, complete exercises, to do formative quizzes, to watch the embedded/recorded videos, to go through additional material such as the reading list, etc.), and s/he can communicate asynchronously with the tutor, e.g. via emails (Fig. 4(f)).

Following the phase 2 of the virtual classroom building (as per Fig. 2), it is worth noting that virtual-classroom patterns from (a) to (e) are instances of online learning, while virtual-classroom pattern (f) describes distance learning.

On the other hand, 6 patterns for teaching assessment (Fig. 5) using the core CPS have been identified, as follows:

(i) individual coursework (asynchronous): the coursework (e.g. an essay, a portfolio of works, including report, code, captured videos etc.) is completed by 1student asynchronously and is uploaded onto the VLE platform, once completed (Fig. 5(i));
(ii) group coursework (asynchronous): in case of n*students working collaboratively on their group assignment, they can communicate with each other via all the CPS multimedia channels, prior to upload their work onto the VLE platform (Fig. 5(ii));
(iii) group demo (synchronous): in case of n*students-to-m*examinators, the demo is of a meeting style, where all the synchronous CPS communication channels are open between all the students and examinators (Fig. 5(iii));
(iv) project presentation (synchronous): in case of 1student-to-m*examinators, the presentation has a meeting style, with all the synchronous CPS communication channels available for both student and examinators (Fig. 5(iv));
(v) oral exam (synchronous): in case of 1student-to-m*examinators, the exam follows the meeting style via CPS L3, but L1 and L2 module content is not made available to the student for the exam duration (Fig. 5(v));
(vi) written exam (synchronous): in case of 1student doing a remote exam, an authentication check could be performed through the CPS by the examinator(s) before and/or after the exam is uploaded onto the VLE platform by the student (Fig. 5(vi)).

Following the phase 3 of the virtual classroom building (as per Fig. 2), it is worth noting that virtual-classroom

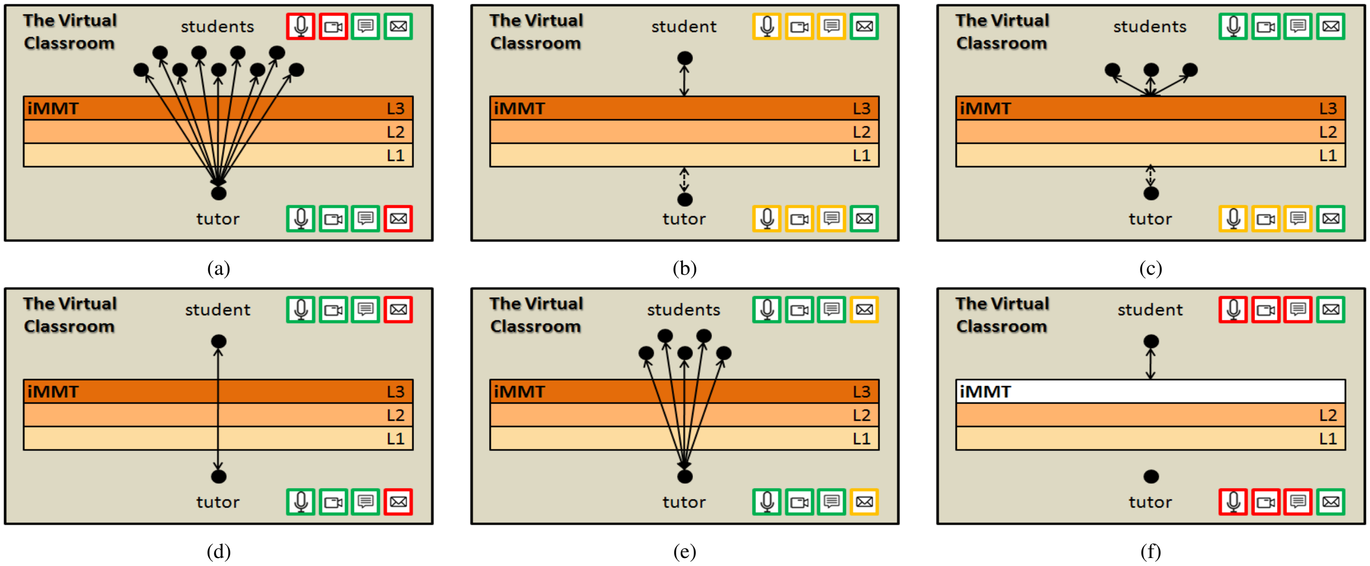

Fig. 4. Identified virtual-classroom patterns for the interconnection of CPS interactive multimedia tools in case of (a) lecture; (b) lab work; (c) workshop; (d) tutorial; (e) seminar; (f) homework.

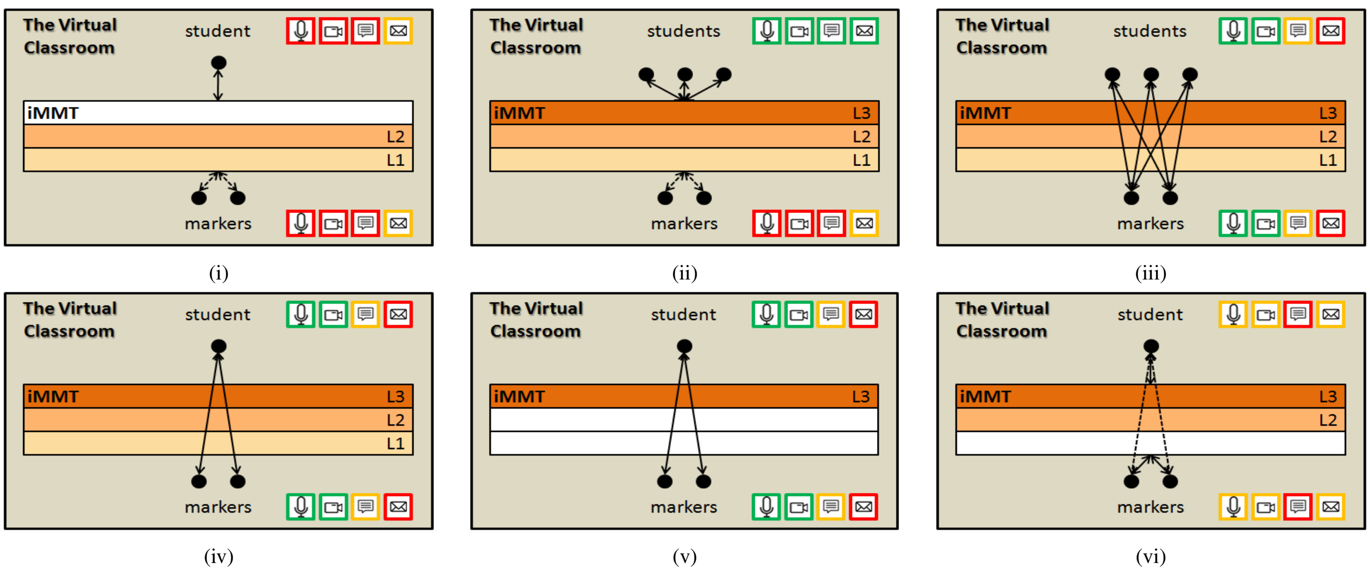

Fig. 5. Identified virtual-classroom patterns for the interconnection of CPS interactive multimedia tools in case of (i) individual coursework; (ii) group coursework; (iii) group demo; (iv) project presentation; (v) oral exam; (vi) written exam.

patterns (i)-(ii) are cases of asynchronous assessments, while virtual-classroom patterns from (iii) to (vi) are examples of synchronous assessment.

For all these established interactive patterns as illustrated in Figs. 4-5, the CPS communication modalities that are used by default are represented within the green squares; the ones that might be used on-demand are depicted in the amber squares; and the ones that are not in use for a specific pattern are then displayed within the red squares.

To further evaluate these proposed patterns, a number of experiments was carried out. In particular, the different (a)-(e) patterns for synchronous T&L activities have been applied respectively to 40 video-calling sessions, where 33 calls used Microsoft Teams (v.1.300.26064, 64 bit) and 7 calls used Cisco WebEx (v.40.9.8.3), with 1 tutor and 1:n* students in the virtual classroom. The related technological solutions have been analysed and compared, as reported in Table II.

TABLE II
EXCERPT OF TECHNOLOGICAL SOLUTIONS FOR THE PROPOSED PATTERNS

T&L Patterns	MS Teams	WebEx
lecture	call up to 500 students	call up to 1,000 students
lab work	ad-hoc ‘meet now’ call	virtual ‘personal room’ call
workshop	calls through team’s additional channels	calls within meeting’s breakout sessions
tutorial	1-member-team call	‘meeting Pro 1000’ call

IV. CONCLUSIONS

Virtual classrooms on a connected campus have become a reality in the current, socially distanced situation, leading to an increased use of multimedia technologies and to a new educational cyber-physical system. However, these IT tools should not be considered as a barrier in-between students and/or lecturer, but as a transparent medium to aid students to communicate with peers and/or tutor and to access the module content to learn the module core knowledge. For this purpose, we have presented in this paper the life-cycle to build the virtual classroom efficiently and, in particular, different patterns to interconnect interactive multimedia softwares for both quality delivery and assessment modules in computer science education.

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