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Mulsemmedia in Telecommunication and Networking Education: A Novel Teaching Approach that Improves the Learning Process

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Abstract— The advent and increased use of new technologies, such as innovative mulsemmedia and multi-modal content distribution mechanisms, have brought new challenges and diverse opportunities for Technology Enhanced Learning (TEL). NEWTON is a Horizon 2020 European project that revolutionizes the educational process through innovative TEL methodologies and tools, integrated in a pan-European STEM-related learning network platform. This paper focuses on one of these novel TEL methodologies (i.e. mulsemmedia) and presents how NEWTON enables mulsemmedia-enhanced teaching and learning of STEM subjects, with a particular focus on Telecommunication and Networking related modules. The paper also discusses the very promising results of NEWTON case studies carried out with engineering students across two different universities, in Spain and Ireland, respectively. The case studies focused on analyzing the impact on the learning process of the mulsemmedia-enhanced teaching in the context of Telecommunication and Networking modules. The main conclusion of the paper is that mulsemmedia-enhanced education significantly increases students' learning experience and improves their knowledge gain.

Index Terms— Mulsemmedia, Technology Enhanced Learning, Learner Experience, Telecommunication, Education.

I. INTRODUCTION

IN the current digital era, technology enhanced learning (TEL) is experiencing a fast and complex evolution that creates new trends in learning environments and allows students to learn more efficiently than ever. Reports and surveys show that e-learning and mobile learning are continuously growing in popularity [1] and mention the increase in the adoption of TEL (e.g. learning management systems (LMS) are growing at a significant rate and are expected to exceed \$23.21 billion by 2023). The latest advancements in Information and Communication Technologies have enabled a wide range of e-learning methods by providing learners with diverse devices, systems, solutions and methodologies in order to enhance their learning experience.

In Science, Technology, Engineering and Mathematics (STEM) subjects, special attention is paid to practical training that facilitates the deep understanding of design procedures, practical limitations, and engineering trade-offs. Different current innovative technologies and approaches, including multisensory augmented and virtual reality, or game-based

learning, constitute a perfect playground for experimentation - one of the main components of engineering education. Designing multisensory course content could cater to a mixture of abilities and contribute towards improving inclusion in education environments. Moreover, it could trigger an embodied and enactive approach to learning - where knowledge is not only mediated by human senses, but it is acquired by doing. The main argument for this is that the human brain is multisensory [2] and the multimodal information it processes facilitates acting in the world. Thus, we argue that learning can be reinforced and enriched by stimulating multiple sensory channels.

In order to allow students to experiment theoretical concepts in STEM subjects, while increasing their satisfaction level and their connection to real world conditions, we propose NEWTELP - an intelligent LMS that combines a multisensory approach with innovative feedback processes, thus facilitating knowledge acquisition with all human senses. NEWTELP is the result of Networked Labs for Training in Sciences and Technologies for Information and Communication (NEWTON), a large Horizon 2020 European project that explores the effectiveness of multisensory immersive learning environments. NEWTON integrates Virtual and Fabrication (Fab) Labs, specifically dedicated to STEM subjects. This is motivated by statistics that show the need for promoting STEM subjects, including the ones that relate to difficult but highly important topics, such as ones pertaining to Telecommunications Engineering [3].

Research that goes beyond visual representation in learning is limited, especially in a digital context [4]. NEWTELP addresses this gap and makes use of recent technology advances in wearables and network speeds that allow for a natural next step towards the evolution of learning through multisensory stimulation. The result is a framework that links all stakeholders in education and disseminates new teaching scenarios and educational activities making use also of mulsemmedia [5]. A set of trailed scenarios, based on the NEWTELP platform, showed promising results for secondary schools and for tertiary education institutions - at both undergraduate and postgraduate levels. Different platform components (Adaptation, Gamification and Personalization - see Figure 1) were tested in the context of undergraduate classes with over 100 students [6] [7].

In this paper, we demonstrate the versatility, complexity and the potential of the NEWTELP platform in changing current pedagogical practices in Telecommunications and Networking-related modules. Our solution employs

multimedia as part of a constitutionalist perspective on learning that sees perceptions, approaches and outcomes as simultaneously present in the student's awareness. We tested the validity and transferability of our approach in two different European universities, Dublin City University (DCU), Dublin, Ireland and University of Basque Country (UPV/EHU), Bilbao, Spain, and we report the results in this paper. NEWTON's multisensory approach resulted in increased motivation of students and increased academic performance. Noteworthy is the fact that due to the success of this innovative teaching approach it is currently adopted by universities in Slovakia and Romania.

The structure of the paper is as follows. Section II familiarizes readers with the employment of multisensory stimulation in education, section III presents an overview of multimedia-enhanced learning is enabled in this platform. Section V describes case studies undertaken with students that were presented with multimedia-enhanced content in the context of Telecommunications and Networking modules. Lastly, section VI draws conclusions and identifies opportunities for future work.

II. MULTISENSORY STIMULATION IN EDUCATION

Traditional learning is often a unisensory experience, although our interaction with the surrounding environment is multisensory. Multisensory learning theories argue that the stimulation of various sensory channels reinforces the learning process. Previous findings show that when an individual is provided with various sensory cues, her/his cognitive load is reduced and learning is improved (memory, perceptual and implicit learning, training outcomes are facilitated) [2].

Moreover, multisensory approaches can benefit individuals with a variety of disabilities, such as sensory or cognitive disabilities. In these cases, both perceptual and mental images are characterized by high rigidity, are fragmented, incomplete and limited. This is due to the slow and unorganized perceptual activity, to low sensitivity, and also to the difficulties in the analysis and synthesis processes. Therefore, in the educational activities performed with children with intellectual disabilities, it is imperative to stimulate the primary cognition through multisensory stimulation, training, clarification and correction of representations. Children with dyslexia can also benefit from multisensory teaching techniques as these can help them: 1) absorb new information by making abstract concepts more concrete; 2) memorize sequences by enriching them with multisensory dimensions (e.g., sights, sounds, smells, movements). In [8], the authors present a teaching programme for learners with dyslexia that includes multisensory stimulation.

Whilst neurologists and psychologists have advanced the field of multisensory perception, when it comes to digital setups, the development on multisensory experiences is still in its infancy. However, recent significant advances in technology (e.g. devices, network speeds) enable great opportunities to improve sensory experiences in various educational settings. Digital multisensory learning environments, where learners can experiment with the taught material, can promote

motivation and engagement of students - aspects that have a paramount importance in the learning process. NEWTELP is the first platform of its kind that promises to shape future education by leveraging adaptive streaming technology and multisensory stimulation.

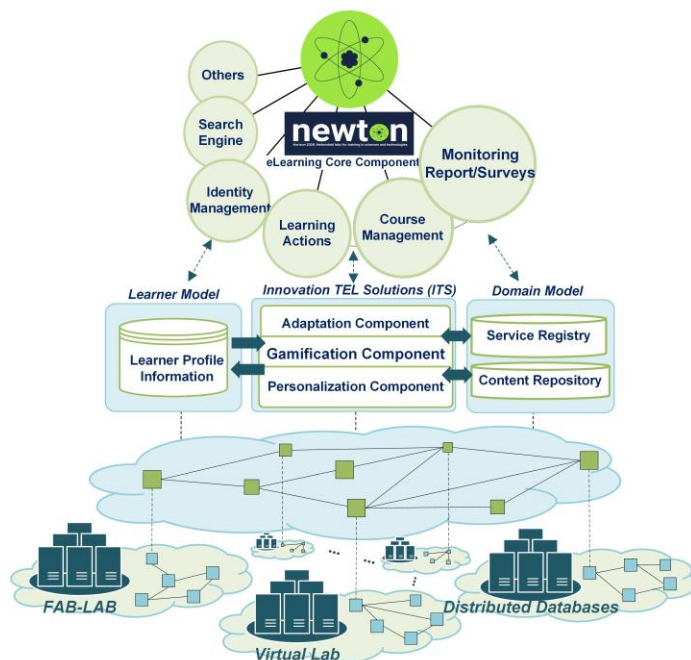


Fig. 1: NEWTELP Platform - Architecture

III. MULTIMEDIA: OVERVIEW AND CHALLENGES

The term *multimedia* [9] - multiple sensorial media - was introduced relatively recently and represents a type of multimedia that involves senses beyond audition and vision. Multimedia content includes in addition to audio-visual components, metadata to trigger stimuli for other senses (e.g. touch, smell, taste). Thus in the development of a typical multimedia delivery system, one needs to consider the following workflow: 1) creation of the multimedia content, 2) content distribution and reception, 3) rendering the content to the end-user via a collection of devices targeting different senses (e.g., haptic chairs, olfactory displays, airflow generators, etc.) [10].

Multimedia delivery brings several challenges that need to be addressed. One of them comes from the lack of guidelines for creating effective multisensory content. Major challenges are imposed by communications issues related to the delivery of multimedia content over existing heterogeneous network environments. In this context, the synchronization between the different multisensory components becomes a major challenge. A temporal order of the multisensory effects must be ensured since "out-of-sync" effects lead often to a decrease in user quality of experience (QoE) levels [11].

Moreover, compared to multimedia content, multimedia introduces additional components that relate to the extra-senses being stimulated, thus bringing an overhead to the communication. In the particular case of multimedia, there is much research that studied QoE issues in different network conditions and proposed solutions to increase QoE levels.

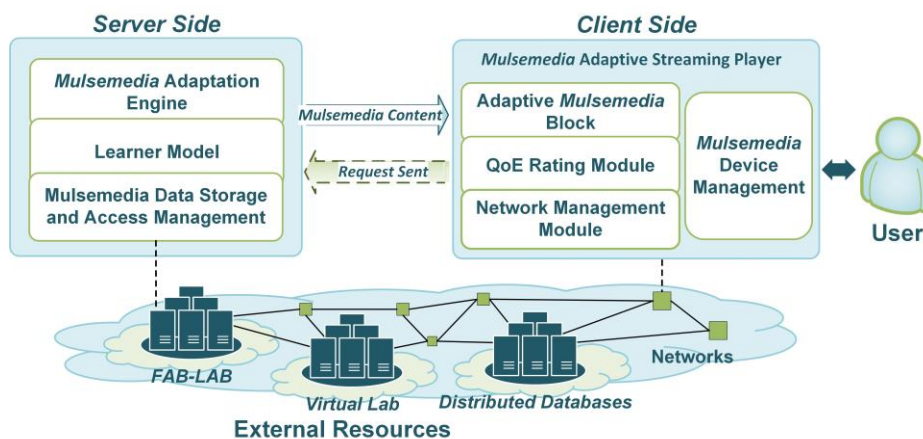


Fig. 2: Mulsemedia component - architecture

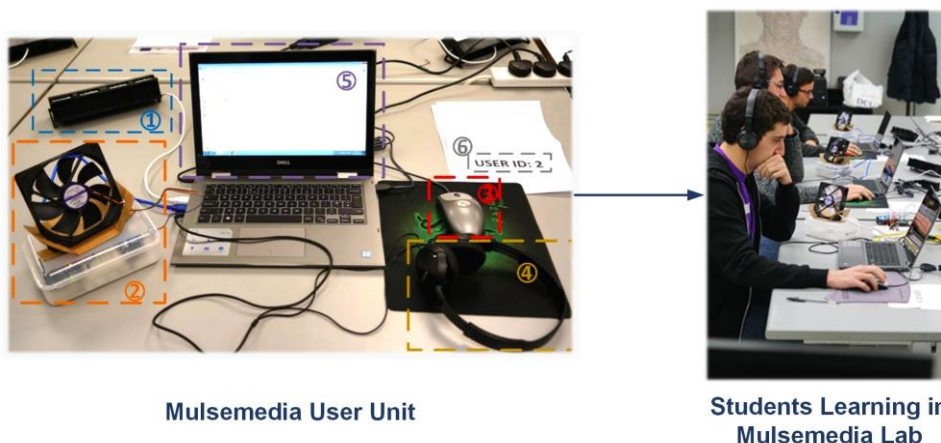


Fig. 3: Mulsemedia lab

There is a significant number of proposed adaptive multimedia delivery solutions that enable real-time adjustments of the content distribution process, addressing issues like network variability, energy consumption and user preference in order to increase user QoE [12]. We argue that this adaptation principle can also be used in the case of mulsemedia delivery and this was the starting point of the solution designed in the context of the NEWTON project, which is further detailed in section IV.

IV. ENABLING MULSEMEDIA-ENHANCED LEARNING VIA THE NEWTELP PLATFORM

A. Introduction to the Learning Platform

NEWTELP is a pan-European learning platform enabling delivery of STEM subjects to a large variety of learners from primary, secondary and vocational schools, third level education institutions and special schools for people with disabilities. This learning platform integrates a set of distributed labs, existing state-of-the-art teaching labs (e.g. Fab Labs) and the newly created Fab Labs or Virtual Labs - as a result of the project. NEWTON Fab Labs are unique in comparison to the existing ones as they provide the Fab Lab experience anywhere, anytime and for everyone by enabling

remote access to such facilities and by supporting students with special educational needs. Figure 1 presents an overview of the NEWTELP platform functional architecture. This platform has all the capabilities of a classic LMS, enabled by the block *eLearning Core Components*. As presented in Figure 1, this block encapsulates functionalities like: *Identity Management* (for managing the roles supported by the platform: student, teacher, administrator), *Learning Actions* (that allows students to select actions related to the learning process), *Course Management*, *Monitoring and Report/Surveys* and *Others* (e.g. integration of social media). We stress here that the NEWTELP platform is not a run-of-the-mill LMS, but one enhanced with intelligent attributes and functionality such as support for gamification, personalisation and adaptive (mulse)media delivery. It also allows students to experience Virtual Labs and Fab Labs, offering the possibility to integrate innovative TEL solutions in order to increase the overall learning experience and performance.

B. Mulsemedia-enhanced Learning with the NEWTELP Platform

In the context of the NEWTELP platform architecture, the mulsemedia delivery solution is part of the *Adaptation* component. Figure 2 presents the detailed architecture of this mulsemedia delivery solution, which follows a client-server

model. At the client-side, one of the main components is the *Adaptive Mulsemmedia Block*, which embeds the logic for adapting the mulsemmedia content based on the user operational characteristics. These characteristics are collected from *Mulsemmedia Device Management*, *Network Management* and *QoE Rating* modules and include:

- Network characteristics such as delay, loss, jitter
- Display device specifications (e.g. main type - mobile, laptop, desktop - , screen resolution, battery information)
- Multisensory devices type (e.g., audio, haptic, olfactory, etc.) and subtypes (i.e. device name).

The *Mulsemmedia Device Management* component detects and controls multisensory devices. It acts as an abstraction layer between the NEWTELP platform and the actual devices in order to allow for extensions: the platform will not be bound to the usage of certain multisensory devices only; instead diverse devices could be easily added.

The proposed mulsemmedia delivery solution has as its main component at the server-side the *Mulsemmedia Adaptation Engine* that also embeds adaptation logic and is based on information received from the *Learner Model*. This information is related to learner operational characteristics and learner profile (mainly affective and sensory characteristics of the learner, but also possible disability-specific characteristics).

Mulsemmedia Data Storage and Access Management provides suitable access mechanisms to the mulsemmedia content that is stored in the Virtual Labs or distributed repositories connected to the NEWTELP platform.

V. MULSEMEDIA-ENHANCED TEACHING IN TELECOMMUNICATIONS AND NETWORKING

In the context of the NEWTON project, we aimed to employ mulsemmedia as a TEL methodology in delivering Telecommunication and Networking modules in tertiary institutions.

DCU students' interest level for the Energy Harvesting, an emergent topic in the area of Green Communications and Networking, was very low. The lecturer delivering the topic was interested in finding a different approach as an effective alternative to PowerPoint presentations, where the content was highly theoretical. Mulsemmedia content was developed in NEWTON, consisting of videos presenting topic-related concepts enhanced with multisensory effects (e.g. one audiovideo scene, enhanced with wind effect, showed how wind turbines are used in the context of vehicular networks for powering road-side units). The content was delivered to 40 undergraduate engineering students from DCU and showed that the mulsemmedia-based approach encouraged students' motivation and fun, producing stronger test scores and reducing students' boredom and reticence to learning [6].

The lack of appropriate importance given to standards in Telecommunication and Networking education, as well as the lack of learner appeal, is signalled in [13], an extensive study that analyzed the third-level curricula across a large number of institutions. Since our vision is that mulsemmedia can be part of innovative teaching practices, to address the identified shortcomings, we developed content to assess its efficiency in the learning process of telecommunications standardization.

Next, we present a case study carried out with postgraduate students that were exposed to such content.

A. A Mulsemmedia-enhanced Telecommunication Lesson - Case Study

Participants. For this study, we recruited 42 participants. All were Master students, who attended the *Performance on Telecommunications Networks* course at the UPV/EHU, Spain (22 participants) and *Performance of Data Networks* at DCU, Ireland (20 participants). The topic and the content of the taught material was the result of intensive discussions and collaboration between the lecturers on both sides - DCU and UPV/EHU.

Lesson design. The pedagogical objectives of the lesson were for students to be able to: 1) Describe the concept of Quality of Experience (QoE) and its influencing factors as defined by International Telecommunication Union - Telecommunication Standardization Sector (ITU-T) [14]; 2) Critically analyze different QoE measurement techniques such as objective quality assessment, physiological/cognitive-based techniques, subjective quality assessment (with the emphasis on the ITU-T defined techniques). The teaching material was split in two equal-sized parts. A part of the lesson was delivered using a traditional audiovisual teaching method based on a Microsoft Powerpoint presentation. The other part was delivered in an experimental setup where we employed mulsemmedia.

During the mulsemmedia-enhanced lesson, students were exposed to a generic evaluation of the QoE, where they watched a series of videos enhanced with various combinations of sensory effects (from no effects to all effects - haptic, airflow, olfaction - in one video). At the end of each video, they were asked to assess the perceived quality. Based on research described in Section II, our hypothesis was that multisensory-training protocols can enhance the learning process by communicating abstract notions (such as the QoE concept and measurement techniques) through different media. Moreover, we argue that by employing mulsemmedia, students can get a better understanding of the fact that QoE, defined as "*the degree of delight or annoyance of the user of an application or service*" [14], may be influenced by user expectations and context as stated by ITU-T (e.g. will a bad smell negatively influence the *degree of delight or annoyance*/how about a pleasant one? Does a combination of haptic and airflow effects provide a better experience than haptic alone?).

Apparatus. This mulsemmedia-enhanced experiential part of the lesson was delivered in a mulsemmedia lab that was set up in both locations (UPV/EHU and DCU) and was composed of multiple mulsemmedia user units. Each such user unit in the mulsemmedia lab (illustrated in Figure 3) consisted of the following components:

- A computer case fan (12V) acting as an airflow generator. The fan was connected to an Arduino board that allowed the control of speed, air flow intensity and stimulus duration.
- A smell dispenser was in charge with the distribution of olfactory stimuli by controlling the operation of four small rear fans. Rotation duration and intensity of each

fan was adjustable. Four different aroma cartridges were used, in line with the multimedia content offered to the students.

- A haptic mouse was used that enabled programmable control of its vibration type, intensity and duration.
- Headphones were used to deliver noise-free high quality audio content to the students.

Data collection. The above described lesson was delivered to students during their normal lecture hours. The only difference between the two universities was the language used: Spanish in case of UPV/EHU and English in case of DCU.

Our interest is to evaluate whether mulsemmedia experimental sessions can be used as a more involved way of learning and as a fun, faster and more effective approach to study theoretical (i.e. standardization) concepts. To investigate this, we devised a set of assessment materials that students were required to fill in at the end of their lecture: 1) a satisfaction questionnaire assessing their learning experience and their evaluation of the enhancement brought by the mulsemmedia content; 2) a test to assess the knowledge gained by the students during the lesson.

The satisfaction questionnaire was built in collaboration with experts in Psychopedagogy from the University of Bucharest, Romania and its goal was to collect relevant data to be used in the investigation of the following aspects:

- What is the impact of mulsemmedia on the learning experience?
- Does mulsemmedia have potential to be accepted as a TEL methodology?

This questionnaire was comprised of the following questions: **Q1:** *The multisensory experience helped me to better understand the concepts;* **Q2:** *The multisensory experience helped me to better assimilate the concepts;* **Q3:** *The multisensory effects were disturbing for me during the class;* **Q4:** *I enjoyed the multisensory experience during the class;* **Q5:** *The multisensory experience did not improve my learning experience;* **Q6:** *The multisensory experience helped me to be more practically engaged in the learning process;* **Q7:** *I would like to have more classes/ labs/ courses that include multisensory experience.* A 5-point Likert scale was used for the answers to these questions as follows: *Strongly Disagree, Disagree, Neutral, Agree and Strongly Agree.*

The test was designed to assess the student knowledge at the end of the lesson. The goal of the test was to compare students' performance in the questions related to the course content which was presented using mulsemmedia with that in the questions associated with the course aspects that were taught without mulsemmedia support. The test contained 4 open-ended questions and 4 multiple choice questions, where in both categories, 2 evaluated the knowledge gain through the traditional teaching approach and 2 assessed the knowledge gain through the mulsemmedia-enhanced teaching approach. Each question carried a maximum of 10 marks.

B. Results and Analysis

1) Mulsemmedia Impact on the Learning Experience: As stated previously, one of the main goals of our study is to assess whether students' learning experiences can benefit from mulsemmedia sessions. Our motivation for this approach is based on previous research indicating that positive emotions correlate positively with intrinsic motivation, effort, learning behavior, and performance. Since creating interactive lessons that appeal to students through their senses contributes to affective engagement, our hypothesis is that mulsemmedia can lead to an increase of enjoyment that can contribute to a better content understanding and cognitive engagement.

The frequency of answers given to questions from the satisfaction questionnaire - considering both institutions (DCU - left; UPV/EHU - right) - is represented in Figure 4. We observe blue coloured regions of the bar chart are predominant for positive statements (Q1, Q2, Q4, Q6, Q7) indicating the users' assent. Participants disagreed with negative statements (Q3 and Q5), as suggested by the dominance of yellow coloured regions. To determine whether mean values for these questions are significantly different from the Neutral value, we employed a one-sample t-test. A significance level of $p < 0.05$ was adopted for our study, representing a below 5% probability that the null hypothesis is true (i.e. differences occur by chance); the p-value was computed using SPSS for Windows version 25.0. The descriptive statistics indicate the following mean values: $Mean_{Q1-7} = [3.66, 3.61, 2.79, 3.58, 4.05, 2.21, 3.87]$, while standard deviation (SD) values are: $SD_{Q1-7} = [0.81, 0.75, 0.96, 0.94, 0.61, 0.99, 0.96]$. Since $p < 0.001$ for all questions except Q3, we reject the null hypothesis that the sample mean is equal to the Neutral value and conclude that the students' answers are significantly different from a Neutral opinion.

High means obtained for Q1 and Q2 indicate that students perceive they benefit academically from multisensory experiences implemented effectively in the lesson. Results presented in Section V-B2 come to strengthen their perception. By engaging with multisensory technology, students succeeded in bringing personal meaning - through the senses - to concepts that might have been otherwise perceived as abstract. This is reinforced by answers for Q6, where students appreciated that mulsemmedia provides them more opportunities to become engaged in material. This makes them more excited by the material and more motivated to learn and encourages a student-centered classroom, where students participate in their learning. Q4 (where there is no negative feedback - see Figure 4) indicates that our approach accessed all the learning styles and helped students develop an affective engagement with the material. A statistically significant difference from the Neutral opinion was also obtained for Q5. The students tended to Disagree with the phrase stating that their multisensory experience did not enhance their learning experience. This, corroborated with Q7, where students expressed their preference to include mulsemmedia in other classes, shows that through digital multisensory content, we can assist in building positive learning environments that contribute to reducing boredom in schools, while encouraging student motivation and enjoyment. In Q3, students are Neutral to finding the multisensory experience disturbing. This

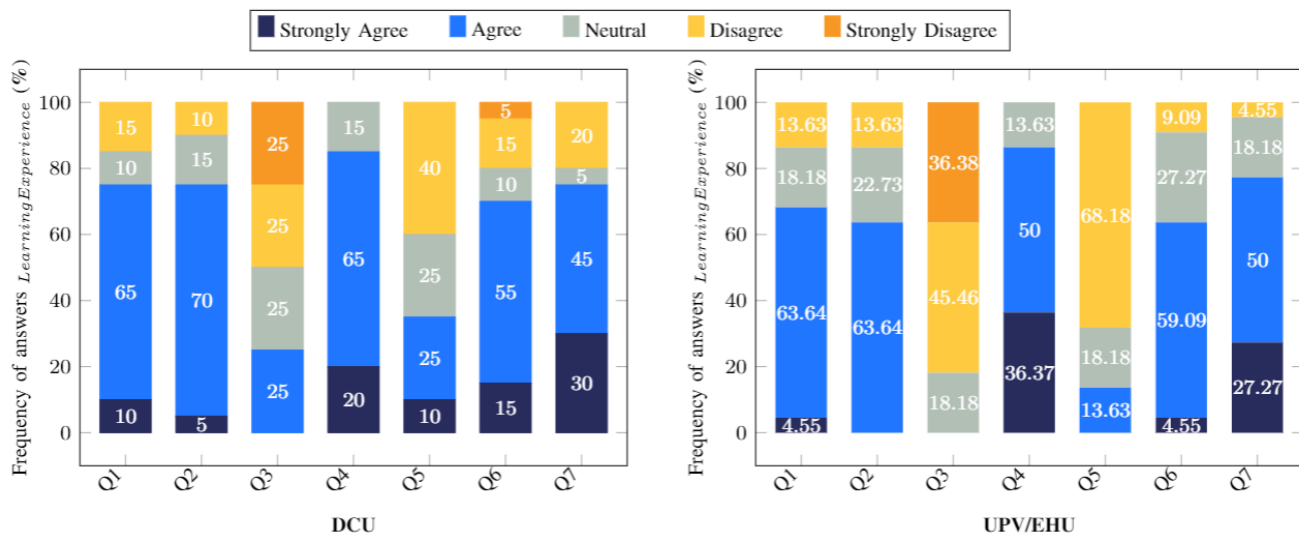


Figure 4 The distribution of answers for the satisfaction questionnaire (left: DCU; right: UPV/EHU)

indicates that although they might have different learning styles or sensory sensitivities, the effects we employed in designing the experience did not affect them negatively.

Considering all these, we can state that mulsemmedia has a beneficial role in helping students to make meaning of abstract concepts related to standardization and increases the likelihood of absorbing them. When the content is delivered in a multisensory way, students become more interested in the lesson and develop a love of learning. This approach makes it possible also to differentiate instruction targeting different learners. Answers to the satisfaction questionnaire and further discussions with the involved lecturers showed an interest in using mulsemmedia as a TEL methodology because it benefits learners cognitively and emotionally.

2) Mulsemmedia Impact on Knowledge Gain: Marks for the test completed by the students at the end of the lesson were allocated by the respective lecturers. Results indicate that the majority of students - 71.43% of students from both universities - had a better average score in questions targeting concepts from the multisensory experiential session compared to questions that were based upon material taught in a traditional way, while 4.76% had similar average scores in questions related to both conditions. Furthermore, the overall average of student marks in questions targeting material taught with mulsemmedia support was 7.41 (out of 10), whereas the overall average of student marks in questions on content taught with the traditional approach was 5.72 (out of 10). To check if there is a statistical significant difference between results obtained in both conditions, we performed a t-test on the collected data. This showed that adding a multisensory component to traditional lessons does influence academic achievement: $t(82) = 3.53, p < 0.001$. We can conclude that results of the test assessing the concepts acquired at the end of the lesson show that mulsemmedia-based sessions are an effective instructional technique. The senses stimulated by the proposed mulsemmedia content provide the contextual cues for students to embed abstract concepts in their memory, leading to knowledge gain.

VI. CONCLUSIONS

Outside the digital world, multisensory learning environments exist and have shown positive results. In contrast, multisensory learning digital setups enhanced with computer controlled sensory devices are far less prominent. Our solution - NEWTELP - fills this gap and brings a novel approach, enhancing the capabilities of classical LMSs with innovative TEL solutions with the aim to revolutionize the educational system. We argue that by enhancing learning content with multisensory dimensions, we can change students perception on topics considered boring (e.g. standardization) and we can increase their engagement in topics that for various reasons (e.g. prohibitively expensive equipment or unfeasible to have/work in a classroom) are very difficult to benefit from practical demonstrations. In the case studies presented here, we specifically target STEM courses, as traditionally they lack the deep engagement that promotes conceptual understanding. Thus, they do not appeal to students who manifest a lack of interest in theoretical material. In this paper, we present promising results obtained with NEWTELP for postgraduate students in the field of Telecommunications and Networking, the impact of mulsemmedia on the learning process being demonstrated through a significant improvement in students' learning experience and knowledge gain.

In designing mulsemmedia educational content, teachers could consider a variety of options; whilst multisensory effects can be linked directly to the concepts aimed to be learnt, they could also simply be added to traditional audio-visual content to create a more enjoyable learning experience. Our case studies demonstrated that both approaches have a positive impact on students learning achievement and experience. Whilst a limitation of our study is that we did not explore the impact of learner characteristics and cultural background on mulsemmedia-based learning, these nonetheless represent worthwhile avenues for future efforts.

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