Improving Student Learning Satisfaction by Using an Innovative DASH-Based Multiple Sensorial Media Delivery Solution

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***Abstract*—Recently, innovative technologies such as Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), and Multi-Sensorial Media (mulsemedia) have introduced new sensorial effects including vibration, smell, airflow, etc. to human life. These effects which have been largely deployed for entertainment, and gaming have positively impacted user satisfaction. This paper explores the potential of mulsemedia in the education context. It describes a novel Dynamic Adaptive Streaming over HTTP (DASH)-based Multi-sensory Media Delivery Solution (DASHMS) which supports adaptive mulsemedia content distribution based on the operational environment which includes network, device, and user settings.DASHMS was evaluated in a real-life educational experiment involving 44 students in an Irish university. The evaluation focused on both learner satisfaction, and the impact on learning. The results demonstrate the potential of adaptive multi-sensorial media delivery to result in a statistically significant increase in user experience. In terms of benefit to learning outcomes however, it was only memory recall which was statistically improved in the experiment.**

***Index Terms*—Dash, learner satisfaction, multi-sensorial media-enhanced delivery, olfaction.**

I. Introduction

According to the most recent Cisco Internet traffic statistics report [1], the global Internet video traffic over IP which accounted for 72% of all IP data traffic in 2017 is expected to reach 80% in 2022 and the virtual and augmented reality traffic will increase more than 12-fold between 2017 and 2022. Moreover, the potential value of immersive technology is no longer a secret as numerous industry reports have forecasted enormous growth for the rich media content exchange market, which can fundamentally enhance the way humans interact with digital and physical real worlds [2].

In multimedia applications, research and technology developments usually target two human senses and focus on improving the image and/or sound quality. This limitation stimulates the disconnection between the user and represented scene, undermining the enhancement of the interaction in digital media through combinations of audiovisual content with one or several types of other stimuli (e.g., haptic, olfactory).

Recently, scholars have begun to analyse the effect of multiple sensorial media (mulsemedia) with the assumption that extending traditional media with additional media components such as tactile, gustatory and/or olfaction may enhance the user experience to some degree [3], [4]. The results of these studies have been positive confirming that user experience is improved when users are exposed to mulsemedia content. However, most mulsemedia-based user experience studies have targeted infotainment as their applicability domain. It is therefore of high interest to study the effect of using multi-sensorial stimuli in areas where the user focus is on different issues beyond personal enjoyment. In an educational setting aspects such as information recall, knowledge retention and its use or application in a different context are of paramount importance in addition to learner enjoyment. This is further underscored by recent reports of decreases in the number of students interested in pursuing third level education in STEM-related disciplines owing in part to perceptions of difficulty. Therefore apart from the learning focus, there has been a push towards increasing learner satisfaction [5] in education in general and in STEM education in particular.

The work described in this paper was performed as part of the EU Horizon 2020-funded NEWTON project.[1] The NEWTON project bridges the gap between the development of latest technologies and classic education by providing educators and students with modern solutions and tools to enable improved and more attractive teaching and learning, with special focus on STEM education.

One of the important outputs of the NEWTON project is a multi-sensorial extension of the Dynamic Adaptive Streaming over HTTP (DASH),[2] a standardized framework for adaptive

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[1]NEWTON project webpage, [Online]. Available: http://newtonproject.eu

[2]ISO/IEC standard 23009-1:2014, Information technology-Dynamic adaptive streaming over HTTP (DASH) - Part 1: Media presentation description & segment formats, 2014.

multimedia delivery which enables dynamic rate adaptation of the streamed content based on network conditions. This paper describes the proposed **DASH-based Multi-Sensory Media Delivery Solution (DASHMS) which extends DASH to support mulsemedia components.** DASHMS engages three or more human senses and **allows for dynamic adjustment of mulsemedia content delivery in order to improve user experience.** DASHMS performs the adaptation according to user operational environment, which can include network, device characteristics and user settings. Previous work has focused on analysis of DASHMSs performance in terms of energy/cost-quality trade off in a simulation setup [6] and in terms of the benefits of synchronisation between different multisensorial effects in a lab environment [7].

This paper describes a study which evaluated a real life student learning process, including user experience when classic audiovisual content was delivered along with multi-sensorial media elements such as tactile, wind and olfaction. The research study targeted Irish postgraduate business school students and delivered mulsemedia content relevant to their background. The study assessed the benefit of employing mulsemedia content delivery in the learning process in terms of learner satisfaction, while also analysing its effect in terms of learning outcome. Specifically, the study analyses for the first time how adaptive multi-sensory-based learning influences the educational process based on different Bloom's taxonomy of learning types: remembering, applying and evaluating, which is highly innovative.

The paper is organized as follows: Section II reviews a number of relevant studies related to mulsemedia and multimedia and their use in student learning. Section III introduces the NEWTON project and Section IV provides an overview of the proposed DASHMS. Section V presents the research methodology of the experimental study and its results. Section VI concludes the paper.

II. Related Works

While multimedia usually incorporates two (bi) or sometimes three forms of media, mulsemedia is considered a type of multimedia involving more than three senses [8]. While it is more commonplace to experience media which is bi-sensoral in nature (using sight and sound), in actuality humans more commonly perceive the world through a combination of our five senses (i.e., sight, hearing, touch, taste, and smell) [8]. Multi-sensory interactions occur at the intersection of two or more sensory modalities and assist in constructing a meaningful representation of the surrounding context. Thus, our experiences of media may be hampered by a reduction in the immersive experience of our senses.

Theoretically, the use of multiple media content elements such as smell and sound may assist in creating a more real-life or comparable context for the student, which relates to the four-component instruction design model for complex learning [9]. It is considered that in an effective mulsemedia environment an integration of sensory input (of a combination of sight, hearing, touch, taste, and smell) with top-down knowledge and memory enables individuals to create, and iteratively validate, complex schema models of the real world. This aids prediction and comprehension of the world around them [10].

As noted by [11], in contrast to multimodal systems, mulsemedia systems consider the media itself and not the modality. Similar to the research path of multimedias effect on the learner [12], studies on the effect of mulsemedia are usually confined to practical demonstrations of use at present. However, the use and application of sensorial feedback in user immersion is growing, with contributions to date focused on olfactory [13] and haptic aspects [14].

An example of such studies was conducted by [15] and used a virtual reality (VR) learning system to study using both olfactory and haptic feedback. Their results noted that students were able to understand the haptic representation and impressed by the additional olfactory information. A mulsemedia VR learning environment which investigated the effects of olfaction on learning, retention, and recall of complex 3D structures is present in [16].

The impact of mulsemedia on educational learner experience is present in the work of [17], in which a local mulsemedia enhanced test-bed based on VideoLan player (VLC) was developed to perform delivery of video content enhanced with haptic, olfaction and airflow effects. The authors found that mulsemedia-enabled video was seen as an enjoyable medium, and students were open to mulsemedia as a technology-enabled pedagogical device. Despite this, the study did not examine the learning efficacy of the technique or the real network environment.

In this experiment, students are asked for feedback based on their experience of varying sensorial media using audio-visual pedagogical content, supplemented with tactile (haptic mouse), airflow (fan) and olfactory (smells) additions. It was hoped that the additions of these effects would improve the immersive experience of the learning context and aid engagement and learner satisfaction. In this sense, immersion refers to the degree to which an individual feels absorbed by or engrossed in a particular experience [18]. It may contribute to the amount of information acquired, skills developed, and subsequent transfer of knowledge to real environments.

There have been a number of studies which provide a rationale for the incorporation of additional sensory experiences to the learning context. Relating to the tactile response, human skin contains a number of different sensory receptor cells that respond preferentially to various mechanical, thermal or chemical stimuli [10]. In providing students with a haptic mouse (which vibrated at times of action within the videos) tactile feedback was provided to students, allowing them to identify several distinct types of sensations.

Olfactory learning is not a frequently considered means of learning engagement, and students do not perceive it to be a primary method of learning or knowledge retention [19]. However, previous studies have reported that compelling olfactory cues have the potential to enhance the sense of presence [20], [21], invoke emotion, and provide salient spatial cues [22]. Previous work has shown that odor, in some cases, can influence the performance on vigilance tasks [23], and mathematical tasks [24], even when the subjects are unaware of the presence of the odor [25]. Murray *et al.* [26] provides a tutorial and recommendations for the evaluation environment, scent types, subjective factors, and video characteristics to conduct olfactory-based mulsemedia QoE evaluation. The use of fans to simulate the outdoor experience has been used in past studies with certain success. Verlinden *et al.* [27] used such an approach to enhance a virtual sailing experience, and noted that participants were more immersed in the experience when a wind machine was added. Considering the use of airflow (fan), [28] noted that in a similar experimental context, the air-flow media can be released either 5s ahead or 3s behind the video content to achieve an acceptable level which did not distract students in their experience.

In this experimental study, a mulsemedia experience was provided to university students which engaged their senses of vision, hearing, smell and touch. The students in question were business postgraduate students. [12] noted that the majority of studies within this domain focused on STEM students, thus this experiment assists in developing knowledge about another category of students.

III. NEWTON Project

The NEWTON project was a large EU Horizon 2020 project which has designed, developed and deployed innovative solutions for Technology-Enhanced Learning (TEL) involving delivery of state-of-the-art STEM content to diverse learner audiences. NEWTON has developed diverse solutions based on innovative technologies for adaptive and personalised multimedia, multi-sensorial media delivery, Virtual and Augmented Reality (VR/AR) learning, Virtual Teaching and Learning Labs (Virtual Labs), Fabrication Labs (Fab Labs) and Gamification-based teaching and learning. These solutions are used in conjunction with different pedagogical approaches including self-directed, game-based and problem-based learning methods.

The NEWTON project has also designed and developed a new learning management platform, NEWTELP,[3] which embeds the NEWTON innovative solutions. NEWTELP allows for cross-European learner and teacher interaction with content and courses and supports fast dissemination of learning content to a wide audience in a ubiquitous manner. The NEWTON project has first designed, then developed and deployed at the level of the NEWTELP platform several proof of concept educational AR/VR applications, games, Virtual Labs and Fab Labs targeting selected STEM subjects. Both the NEWTON educational content and NEWTELP platform have been tested in 20 primary, secondary and third level institutions, including in schools with students with special educational needs, across 6 different EU countries. For example, the Earth course pilot has investigated the use of VR and Virtual Labs when teaching STEM subjects in primary schools, the Fab Lab pilot has demonstrated that remote digital fabrication has improved students learning experience and the Game-based learning pilots have had very positive results in terms of both learning satisfaction and outcome in third-level STEM education. Employing adaptive multimedia content and delivering multiple sensorial media content in educational contexts were reported in [29] and [30], respectively. Finally NEWTON technologies were used to deliver content to both normal development learners and users with special educational needs. Noteworthy is that the NEWTON rich media content and applications were deployed on the NEWTELP platform, including the evaluation procedure, which follows a methodology resulted from the research performed within the NEWTON project and focuses on different aspects, including learner experience, knowledge acquisition and usability.

IV. DASHMS Principle and Architecture

The proposed DASH-based Multi-Sensory Media Delivery Solution (DASHMS) extends DASH in order to enhance user experience with mulsemedia elements. DASHMS not only targets three or more human senses, but also allows for dynamic adjustment of the multiple-sensory media content delivery. DASHMS performs the adaptation according to user operational environment, which can include network, device characteristics and user settings. Inspired by the DASH standard, the proposed DASHMS inherits its advantages in terms of media information organization and extends it by integrating the support for multiple sensorial media components and an adaptive delivery scheme designed to maintain good media streaming quality. The DASHMS architecture, illustrated in Figure 1, involves two main inter-communicating networked components: DASHMS client and DASHMS server. In the context of this paper, the DASHMS server is located at the level of the learning management system (LMS) - the NEWTELP platform (shown in Figure 1).

A. DASHMS Server

The DASHMS server stores multimedia and multi-sensorial media and metadata in order to support DASH-based adaptive content delivery. The DASH Media Presentation Description (MPD) format is employed for metadata to enable adaptive multimedia delivery and a novel multi-sensory MPD [30] - for supporting adaptation of mulsemedia content distribution. Figure 1 illustrates the different multi-sensorial input streams whose segments are denoted x_n^i, where x indicates the sensorial stimulus type (e.g. v - video, o - olfaction, etc.), n - a particular stimulus of type x and i - stimulus segment index. These segments are being generated using either existing *DASH Transform Tools* or the *Mulsemedia Synchronisation Tool* specially developed by the authors, as shown in the figure. For instance the open source tool *MP4Box*[4] can be used to create the video and audio segments and metadata in MPD format according to the DASH standard. The novel *Mulsemedia Synchronization Tool* developed generates the multi-sensory MPD and annotates it in synch with the multimedia content. A *Sender Buffer* enables network transmission of mulsemedia segments following client requests.

[3]NEWTELP platform webpage, [Online]. Available: http://newtelp.eu

[4]mp4box: [Online]. Available: https://gpac.wp.imt.fr/mp4box/

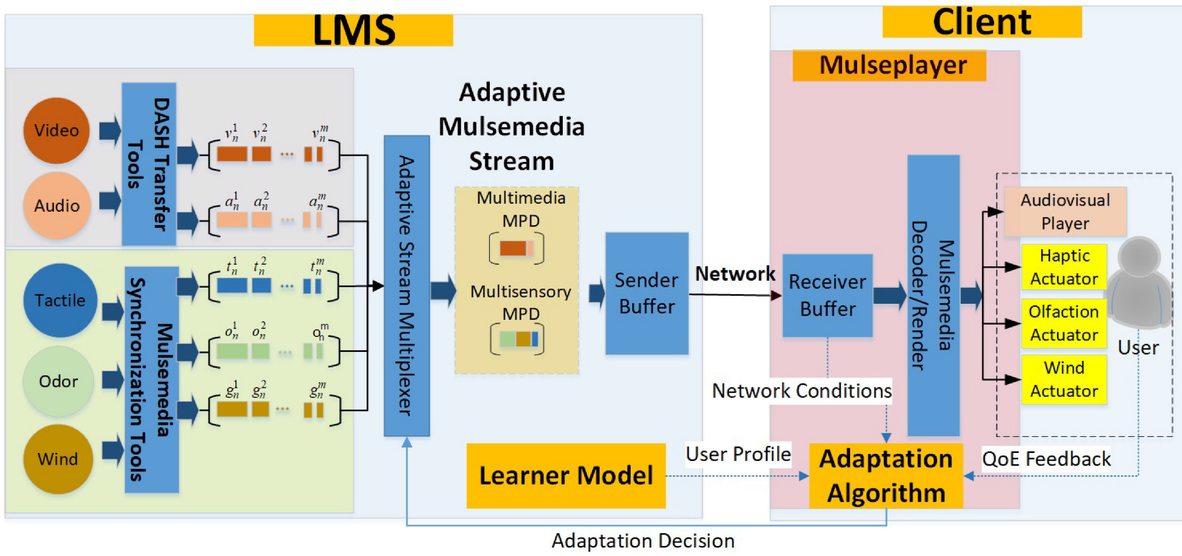

Fig. 1. DASH-based Multi-Sensory Media Delivery System.

B. Multi-Sensory MPD

One of the key aspects introduced by DASHMS is the concept of *multi-sensory MPD (Mulse-MPD)*. Mulse-MPD extends DASH and inherits its hierarchical structure, providing both flexible and reliable content organization. The metadata includes the following components: identification for the different sensory effects, quality/intensity levels, adaptation sets and play periods [6]. However, multi-sensory MPD employs a JSON-based encapsulation for mulsemedia segments instead of the classic XML-based description of sensorial media segment information. This is as the comparative research study on XML and JSON stated that JSON presents better performance for transmission of large number of objects [31] and this is expected for networked DASHMS-based content delivery. The detail design of the multi-sensory MPD is described in our previous work [6].

C. DASHMS Client

As any DASH-based adaptive content delivery is client-driven, the DASHMS client retrieves MPDs and Mulse-MPDs and, based on the *Adaptation Algorithm*, sends requests to the server for multimedia and mulsemedia content. Figure 1 illustrates how a specially designed *Mulsemedia player* (MulseDASH) decodes and renders the multimedia and mulsemedia data retrieved into audio-visual segments and multi-sensory information and plays them by controlling various multi-sensorial display devices to produce stimuli in synchronized manner (i.e. haptic, olfaction, etc.). The MulseDASH player was developed as a web-based mulsemedia player application using JavaScript to enable adaptive mulsemedia delivery. The player follows the client-side architecture illustrated in Figure 1 and extends the MPEG DASH player developed part of the *dash.js* project.[5] The mulsemedia player support Mulse-MPD request and retrieval, network connection and receiver buffer information management, multimedia display, mulsemedia device connectivity, multi-sensorial effect rendering and control and mulsemedia and multimedia synchronization. In particular it is important to maintain synchronization delays low (i.e. below ± 0.07 seconds [7]), in order to achieve high user experience levels [32].

[5]dash.js: [Online]. Available: https://github.com/Dash-Industry-Forum/dash.js/wiki

D. Adaptive Mulsemedia Delivery Algorithm

DASHMS mulsemedia adaptation addresses in conjunction both multimedia and multi-sensory content adjustments.

Following the reception of the requested MPDs from the server, the client parses the received MPD and obtains network condition and user profile information. Next, the adaptation algorithm is employed which performs adaptive selection of content based on the user type inferred from the user profile information and network condition information. After analyzing the combined information, the algorithm selects the corresponding adaptation strategy and controls dynamically the streaming quality for the next requested segment, increasing the utility level of requested mulsemedia data or decreasing it. The utility function employed for each delivery by the DASHMS adaptive algorithm is described in eq. (1).

$$U = w_q * U_q + w_c * U_c \tag{1}$$

In eq. (1) U_q and U_c are utilities associated with multimedia quality and cost/energy consumption and are presented in eq. (2) and eq. (3), respectively. w_q and w_c are weights for the two criteria, representing their importance in the decision algorithm, and $w_q + w_c = 1$. α and β are two positive parameters which determine the shape of the utility function (no unit). Th, Th_{min}, Th_{max} and E, E_{min}, E_{max} are current, minimum and maximum throughput (Mbps) and energy (J), respectively. More details about U_q and U_c are found in [33].

$$U_q = \begin{cases} 0 & \text{if } Th < Th_{min} \\ 1 - \exp\left(\frac{-\alpha * Th^2}{\beta * Th}\right) & \text{if } Th_{min} \leq Th < Th_{max} \\ 1 & \text{if } Th_{max} \leq Th \end{cases} \quad (2)$$

$$U_c = \begin{cases} 1 & \text{if } E < E_{min} \\ \frac{E - E_{min}}{E_{max} - E_{min}} & \text{if } E_{min} \leq E < E_{max} \\ 0 & \text{if } E_{max} \leq E \end{cases} \quad (3)$$

The cost/energy consumption for a real-time media delivery application is computed using eq. (4) [34], where r_d and r_t are energy consumption rates per data unit (J/Mbit) and per time unit (Watt), respectively.

$$E = t * (r_t + Th * r_d) \quad (4)$$

As already mentioned, the DASHMS algorithm performs dynamic adaptive content selection based on the combined impact of network conditions and user profile information. One of the following adaptation strategies is employed:

1) *Quality-aware strategy*: content is requested at the highest quality utility level possible in the given network delivery conditions. This is appropriate for users with high mulsemedia quality preferences.
2) *Energy/Cost-aware strategy*: content is requested at the highest cost/energy utility level possible in the given network delivery conditions. This is appropriate for users with strong energy/cost saving preferences.
3) *Balance-aware strategy*: content is requested such as quality and energy/cost utility is balanced. This is recommended for users who consider a balance between quality and delivery energy/cost.

During deployment, the different strategies were considered by setting the quality and cost/energy utility function weights as follows: $w_q = 0.75$ and $w_c = 0.25$ for quality-aware, $w_q = 0.25$ and $w_c = 0.75$ for cost/energy-aware, and $w_q = 0.5$ and $w_c = 0.5$ for the balanced strategy, respectively.

The DASHMS adaptation mechanism performs dynamic adjustment of both multimedia content and mulsemedia information. The client DASHMS MulseDASH player retrieves multimedia MPDs and Mulse-MPDs via HTTP and learns not only about the media content availability, media types and resolutions, but also about network delivery conditions. The MulseDASH player then builds a timeline, requests segments with default representations and starts playing multimedia and mulsemedia content. The default multimedia segment representations are most appropriate for user devices in use (e.g. 1080p resolution at high 5Mbps bitrate media segment representations for the large screen devices, 720p resolution with 2Mbps average bitrate media segment representations for laptops/tablets, 480p resolution with low 1Mbps bitrate media segment representations for mobile phones, etc.). The MulseDASH player continues fetching subsequent media segments and monitoring network delivery-related metrics. These measurements are used to compute the utility function U based on U_q and U_c, as indicated in eq. (1)–(4). Depending on the adaptation strategies employed, different utility function weights settings are used and diverse values of U can be obtained. The adaptation algorithm identifies the media segment representations which achieve the highest U and the MulseDASH player sends requests to the DASHMS server to fetch these segments.

As the amount of multi-sensorial information is much lower in comparison to multimedia content data (i.e. about two factors of magnitude), the multi-sensorial information adaptation is mostly user profile based. If a user does not like some effects (e.g. olfaction), when the DASHMS client requests multi-sensorial content, only the segments related to the multi-sensorial stimuli liked will be requested (i.e. no olfaction segment). Otherwise, the client will request and the server will send all mulsemedia segments alongside multimedia ones. The Buffered-based Quantized Rate Adaptation Scheme [6] is utilised for the adaptation of mulsemedia information.

V. Experimental Study

In one of our previous DASHMS studies, 37 users from different backgrounds (e.g. students, staff, researchers, engineers) participated in subjective tests to measure their satisfaction levels [7]. Study results showed that the average levels of satisfaction with the multi-sensorial effects are superior or equal to the average levels of satisfaction when no multi-sensorial effects were employed. The study reported in this paper goes further and studies DASHMS's mulsemedia adaptation in terms of both learning experience and learning outcome. A new study was designed and DASHMS was used to deliver real multi-sensorial content in a real-life immersive learning environment to third level education students enrolled in an actual course. The goal of the this research study is to investigate learner experience when educational material involving various multi-sensorial components is delivered to students in different scenarios.

A. Research Methodology

The evaluation included a group of Irish postgraduate students who were exposed to mulsemedia content by using DASHMS. The learning activity took place in a class, during the normal hours of study. A total of 44 students of age 19–25 years from Dublin City University (DCU) Business School, Ireland took part in this research study.

This experiment was designed for up to 24 users per session. The 44 students participated in two separate, but identically run sessions (i.e. 24 students in the first session and 20 in the second session). Each user watched the same 5 video clips, enhanced with a different combination of mulsemedia effects unknown to the participant for each video clip. Thus every user from a session had in fact a unique experience in terms of mulsemedia effect distribution. Figure 12 included in the Appendix presents the combination of mulsemedia effects each user was exposed to for each video.

The study followed all local ethical committee regulations. The plain language statement included a detailed description of the testing scenario, information on study's purpose, participant identity protection info, etc. The participants were asked to sign

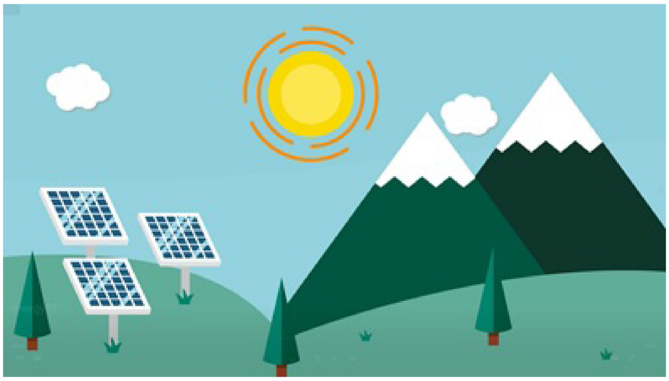

Fig. 2. Video frame from the *Solar* clip.

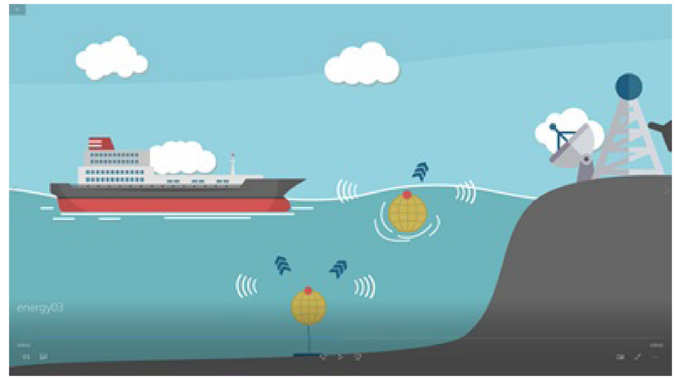

Fig. 4. Video frame from the *Hydro* clip.

Fig. 3. Video frame from the *Kinetic* clip.

Fig. 5. Video frame from the *Renewable Energy* clip.

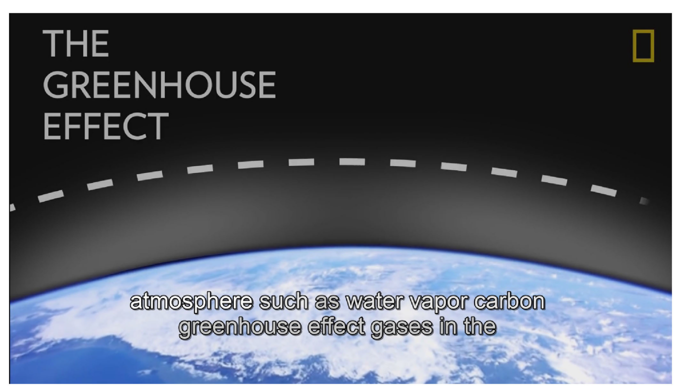

Fig. 6. Video frame from the *Climate Change* clip.

a consent form and they were informed about the procedure regarding data management.

B. Experimental Study Setup

The mulsemedia sequences were generated by enhancing multimedia videos (with a resolution of 1920 × 1080 pixels and a frame rate of 30.3 fps) with multi-sensorial content, i.e., haptic, airflow and/or olfaction effects. These stimuli were selected as previous research studies have indicated them as most influential for information retention in an educational context [17]. The content of the five video clips focused on energy harvesting, renewable energy and climate change and had intermediate scientific level, appropriate for the business module on *Next Generation Management*in which students are required to learn new topics and engage in different modes of learning.

Brief summaries of the content of the clips employed in this study are presented next.

1) *Solar*: Energy harvesting from solar and electromagnetic field sources (see Figure 2).
2) *Kinetic*: Energy harvesting from kinetic sources (e.g. spinning the mobile devices or vibration on a car). A frame from the *Kinetic* video is presented in Figure 3.
3) *Hydro*: Energy harvesting from hydro based sources. Figure 4 presents a screen capture from the *Hydro* clip.
4) *Renewable Energy*: From solar to wind, find out more about alternative energy, the fastest-growing source of energy in the world (see Figure 5).
5) *Climate Change*: Human impact and consequences of climate change for the environment, and our lives. Figure 6 captures a frame from the *Climate Change* video.

Table II details the duration and multi-sensorial effect settings related to each mulsemedia sequence.

Three different scenarios are set with all 5 mulsemedia sequences. In scenario 1, no multi-sensory effect happens during the video display; in scenario 2, all three multi-sensory effects

TABLE I
EVALUATION PROCESS

Ethics requirements	1) Collection of the consent forms 2) Description of the research study 3) Collection of assent forms
Learner process	4) Pre-test questionnaire 5) Learning experience 6) Post-test questionnaire 7) Learner satisfaction questionnaire

TABLE II
DURATION OF THE MULSEMEDIA EFFECT OF EACH VIDEO

Video clip	Duration (minute)	Mulsemedia effects and sync time (second)		
		Air	Haptic	scent
Solar	1:13	5s	9s	Oak:9s
Kinetic	0:53	8s	11s	Diesel:8s
Hydro	1:25	7s	5s	Oak:10s; Ocean:5s
Renewable Energy	3:04	19s	17s	Diesel:8s; Ocean:4s
Climate Change	3:16	64s	16s	Diesel:4s; Ocean:4s; Oak:23s

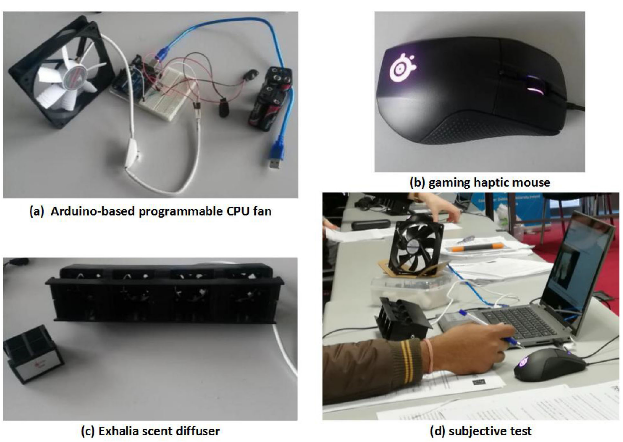

Fig. 7. Mulsemedia Equipment and Test-bed.

(airflow, haptic, olfaction) occur and the olfaction scent is relevant to the video content; in scenario 3, all three multi-sensory effects occur, but the olfaction scent is always *Tutty color* (a scent smell similar to sweet candy), regardless of the video content scent.

To present the mulsemedia effect to the end users, the DASHMS mulseplayer makes use of additional multi-sensory actuator equipment. A gaming haptic mouse, an Exhalia scent diffuser and an Arduino-based programmable CPU fan were used to simulate haptic, olfaction and airflow effects in sync with multimedia content.

According to the content scenario, the multi-sensory effects were manually synchronized with the corresponding sensorial content in the video clips by setting start and end timestamps. Then, the "mulsemedia segment file" is generated by a multi-sensory data annotation tool according to DASHMS.

Figure 7 shows the equipment and test-bed employed in the tests. The Arduino-based programmable controlled fan, Figure 7(a), provides the airflow effect - the fan's on/off state and strength is controlled by a C++ program.

The gaming haptic mouse, SteelSeries Rival, illustrated in Figure 7(b), supports full control of the haptic effect in terms of frequency and duration. The Exhalia device (Figure 7(c)) diffuses scents from each of its four small fans. This subjective test-bed was assembled in a separate room in DCU's Performance Engineering Lab. The testing environment was set up obeying standard ITU-T recommendations P.910[6], P.911[7] and P.913[8].

C. Test Participants

In total, 44 university students participated in the investigation. This number exceeds the recommendations (i.e. 35 participants) of the ITU-T P.913 standard on methods for subjective assessment of audio-visual content quality over the Internet for testing in public environments. These students were postgraduate business students who completed the activity as part of a business management module. The majority of the sample group were aged between 21–25 (63.6%) and Irish (40.9%). Two of the sample indicated they had a visual impairments (such as colour blindness/weakness), while half (n = 22) noted that they wear glasses. The split in terms of gender was 21 females and 23 males. Participants were asked if they had experienced watching movies with sensorial devices which provide effects such as olfaction, haptic and air motion, to which 40.9% (18 students) considered they had experienced some form. Students were asked about elements of their media consumption (e.g. movies etc.), also noting that they consume media via WiFi (88.6%).

D. Result Analysis

1) Learning Satisfaction and Multi-sensorial Experience: Following the experiment, the students were asked to fill out a post-test evaluation of their experience. The majority of respondents (55.6%) were satisfied with the platform used to deliver the mulsemedia content (i.e. NEWTELP), and 31.8% considered themselves neutral. When checking some of the potential limits, 91% considered the video quality to be good or very good. Evaluating the enjoyment of participants with the multi-sensoral nature of the learning experience, 29 of the 44 (65.9%) students indicated *agree* or *strongly agree*, as illustrated in Figure 8. 63.6% of the students indicated they would like to have more classes/labs/courses that include a multi-sensorial experience. This result is in line with the outputs of previous studies which used multi-sensorial stimuli in education [3], [17].

[6]ITU-T R.P.910, Subjective video quality assessment methods for multimedia applications, [Online]. Available: https://www.itu.int/rec/T-REC-P.910/en

[7]ITU-T R.P.911, Subjective audiovisual quality assessment methods for multimedia applications , [Online]. Available: https://www.itu.int/rec/T-REC-P.911/en

[8]ITU-T R.P.913, Methods for the subjective assessment of video quality, audio quality and audiovisual quality of Internet video and distribution quality television in any environment, [Online]. Available: https://www.itu.int/rec/T-REC-P.913/en

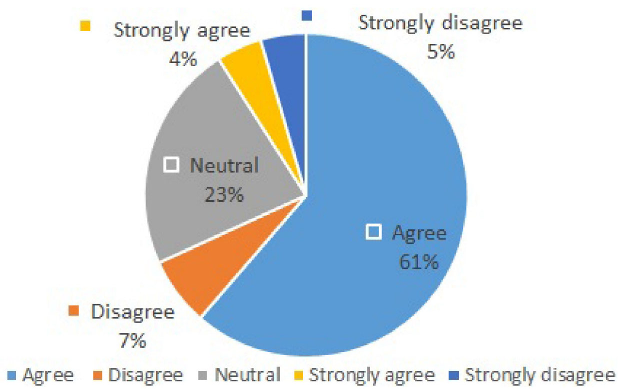

Fig. 8. Participant response related to statement *I enjoyed the multi-sensorial experience during the class.*

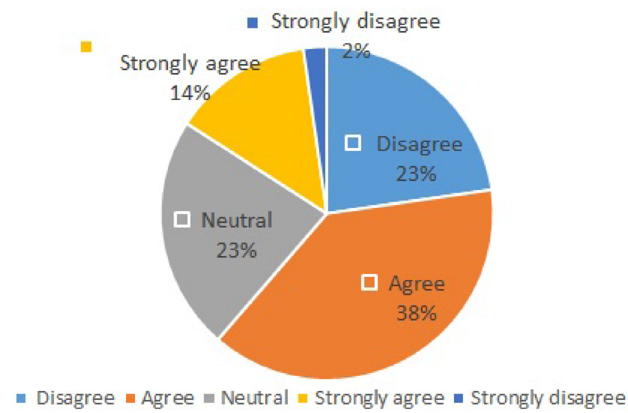

Fig. 10. Participant responses related to statement *The multi-sensorial effects were disturbing for me during the class.*

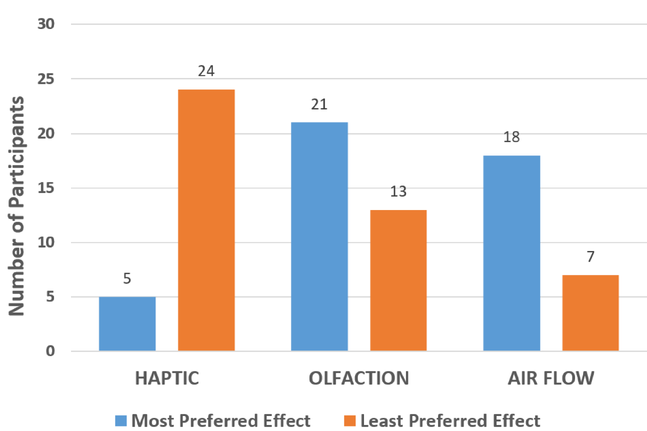

Fig. 9. Participant responses related to statement *The best/worst multi-sensorial effects preferred* - expressed in terms of number of answers.

Considering the mulsemedia experiences in isolation, students noted a preference for the olfactory triggers within the learning experience, with the next preference being airflow/wind (fan). Only 5 students preferred the haptic mouse as the trigger (see Figure 9). This was further echoed when 24 of the students indicated haptic as their least favourite effect.

Mulsemedia is hoped to encourage engagement and immersion into the learning experience, however some results from the post-test survey were interesting. About half of students (52.3%) considered that the sensory equipment or effects were disturbing and that the multi-sensorial experience did not improve their learning experience (see Figure 10). This result is contradicting the students statement regarding enjoyment of the overall multi-sensorial experience (66% agree and strongly agree) and results of previous studies [17]. Feedback from students has helped identify the likely reason behind this result: negative reaction to some stimuli and equipment (i.e. haptic mouse) and their unfamiliarity with the experimental testbed. In the previous studies students familiar with the latest innovative technologies were mostly used in testing.It may be that some adjustment period is needed for students to familiarise themselves with the multisensory experience to reduce any feelings of disturbance.

When the students were asked whether the multi-sensorial experience made them more practically engaged in the learning process, the sample group were clearly divided, however when asked whether it aided their understanding of the concepts, just over half of the students agreed and some remained neutral. This result is in line with those of other studies [17], although the percentage associated with positive assessment here is slightly lower.

2) Learning Outcome: For all scenarios, the participants answered 6 post-test questions after each mulsemedia clip. The post-test questions were created specifically for each video clip on different levels of Blooms taxonomy of learning [35]. Blooms taxonomy (and revised taxonomy) indicates a hierarchical six-level classification system that uses observed student behaviour to infer the level of cognitive achievement [35], [36], [37]. The revision by Anderson and Krathworthl [36] maps six cognitive processes onto a hierarchically specific set of knowledge levels from lower order thinking and cognition to deep higher order thinking (i.e. *remembering, understanding, applying, analyzing, evaluating*, and *creating*). This has been noted as a potentially useful tool for the student self-assessment of learning experience by Athanassiou *et al.* [37] and in the promotion of experiential learning by Cannon *et al.* [38].

For each of the mulsemedia clips, the 6 post-test questions belong to three different levels of Blooms taxonomy [35]. Two questions were created pertaining to memory (*remembering*), two questions had students apply their knowledge from the clip (*applying*) and two questions had students make judgements on the information acquired (*evaluating*) (see Appendix II). Each of the correct answers was associated with 1 or 2 point(s) according to the questions difficulty level (lower order to higher order), and the maximum score was 9 points for *Solar* and *Kinetic* videos, 8 points for each of the other three.

Next the results are analysed based on the number of olfaction stimuli in each clip. When analysing the single scent cases, it was noted that the *Oak* scent used as mulsemedia element along with the *Solar* video in scenario 1 with no-mulsemedia effects was associated with one of the lowest learning outcomes (7.22/9) and scenario 2 matched with the olfaction stimuli achieved the best learning outcome (7.69/9). The matched use of the *Diesel* scent in the *Kinetic* video in scenario 2 resulted in the lowest learning outcome (7.15/9), whereas the use *Tutty color* scent in both *Solar* and *Kinetic* videos had good learning outcome (7.63/9 and 7.5/9).

For the two scents case, it was observed that scenario 1 with no-mulsemedia effects and when associated with the *Hydro* video achieved the best learning outcome (6.31/8), while in scenario 2 with matched scents a similar learning outcome was recorded (6.25/8). However, in scenario 3 with *Tutty color* scent the worst learning outcome (5.81/8) was observed. Additionally in scenario 1 with no-mulsemedia effects and the *Renewable Energy* video a positive learning outcome was obtained (6.63/8), in scenario 2 with matched scent the lowest learning outcome (6.25/8), whereas in scenario 3 with *Tutty color* scent the best learning outcome was achieved (6.94/8).

For three scents case, in scenario 1 with no-mulsemedia effects and *Hydro* video, the best learning outcome was obtained (6.88/8), in scenario 2 with matched scent a lower learning outcome (6.31/8), whereas in scenario 3 with *Tutty color* scent the worst learning outcome in this category was recorded (6.19/8).

Compared to scenario 1 with no-mulsemedia effects, the content without the *Diesel* smell in matched scent scenarios had an increase of 2.98% in terms of learning outcome, whereas when the *Diesel* smell was present in matched scent scenarios a decrease of 5.12% in learning outcome was recorded. Compared to scenario 3 with *Tutty color* scent, content without *Diesel* in matched scent scenarios an increase of 3.72% in terms of learning outcome was noted, whereas when *Diesel* was present in matched scent scenarios learning outcome decreased by 4.55%. These results suggest that the stimuli type impacts learning outcome and participants prefer positive stimuli (e.g. nice smells). However, when statistically examined, all the t-tests analyses studying the differing effects on learning outcome related to the scenarios for the five mulsemedia clips did not achieve high statistical significance. Further work may be required to complement the findings in this work and those of previous studies [3].

Figure 11 presents the average percentage of correct answers to the different questions of the three Bloom taxonomy types. *Remembering* questions had 75.78% correct ratio, *applying* questions had 73.52%, whereas *evaluating* questions a 86.44% correct ratio. These results suggest the proposed approach works very well for all question or learning type, and most effectively of those tested for the evaluatory questions. This is a positive result on the potential of the mulsemedia learning environment as evaluating is one of the higher order learning levels on Bloom's taxonomy and is more desirable than remembering. We would further argue that for Masters level business students, the ability to understand and evaluate new concepts as demonstrated through evaluatory questions is a valuable skill. This result also adds to the knowledge in this area as, to the best of authors knowledge, no other research has performed an analysis of the multi-sensory stimuli effect on learning based on different Bloom's taxonomy levels.

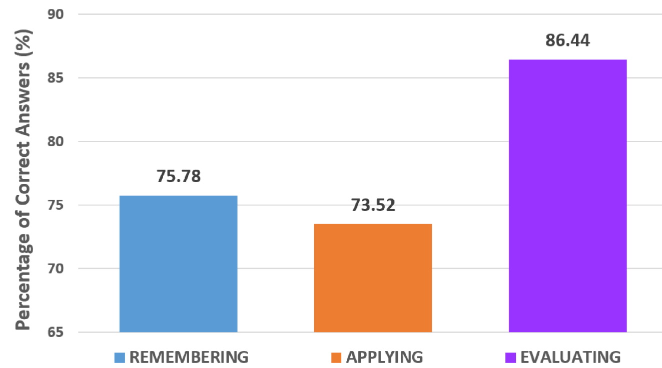

Fig. 11. Percentage of correct answers to questions of different Bloom taxonomy types: remembering, applying and evaluating.

VI. Conclusions, Discussion and Future Work

This paper introduced and described a novel DASH-based Multi-sensory Media Delivery Solution (DASHMS) which supports the adaptive distribution of mulsemedia content. DASHMS enables the consideration of user operational environment aspects such as network conditions, device characteristics and user settings. DASHMS was evaluated in a real-life study involving third level education students who have learned about energy harvesting and conservation. The evaluation concluded that there is a statistical significant increase in learner satisfaction when exposed to multi-sensorial stimuli. Although good, the overall impact of the use of mulsemedia on the learning outcome was not statistically significant. However, the paper also included an innovative study of the effect of multi-sensorial stimuli on learning in terms of three learning types in the Bloom's taxonomy: *remembering, applying* and *evaluating*. The important finding was that very good results were obtained for all types (i.e. over 75% correct answers to questions), but *evaluating* achieved the best results (i.e. over 85% correct answers). It is also important to note the fact that the students were eager to embrace mulsemedia delivery as an important component in TEL process. This implies that DASHMS-based adaptive multi-sensorial media delivery in particular can be used as a complement to the classical teacher-based approach to encourage students to learn.

Authors of [39] established the multi-modal principle as deeper learning occurs when subjects are exposed to more modalities than one. While the students enjoyed the experience, it is unclear if a synergistic effect on the learning effect has occurred. Future work will consider personalisation of multi-sensorial stimuli delivery with the hope that learners will appreciate more the use of mulsemedia effects they like the most and therefore they will benefit in terms of learning outcome. Additionally how various olfaction stimuli affect users according to their perceived pleasant/displeasing effect will also be studied. It would also be interesting to explore the effects on learning over time as students become more customised to this mode of learning.

Video clips	Video 1	Video 2	Video 3	Video 4	Video 5	Groups
User 1	None	Tutty color	M	None	Tutty color	
User 2	M	None	Tutty color	M	None	
User 3	Tutty color	M	None	Tutty color	M	
Video clips	Video 4	Video 5	Video 2	Video 3	Video 1	
User 4	None	M	None	M	Tutty color	
User 5	M	Tutty color	M	Tutty color	None	
User 6	Tutty color	None	Tutty color	None	M	1
Video clips	Video 4	Video 5	Video 1	Video 2	Video 3	Groups
User 7	None	Tutty color	None	Tutty color	M	
User 8	M	None	M	None	Tutty color	
User 9	Tutty color	M	Tutty color	M	None	
Video clips	Video 3	Video 1	Video 2	Video 5	Video 4	
User 10	M	Tutty color	None	M	None	
User 11	Tutty color	None	M	Tutty color	M	
User 12	None	M	Tutty color	None	Tutty color	2
Video clips	Video 1	Video 3	Video 2	Video 4	Video 5	Groups
User 13	None	M	Tutty color	None	Tutty color	
User 14	M	Tutty color	None	M	None	
User 15	Tutty color	None	M	Tutty color	M	
Video clips	Video 2	Video 3	Video 1	Video 4	Video 5	
User 16	None	M	Tutty color	None	M	
User 17	M	Tutty color	None	M	Tutty color	
User 18	Tutty color	None	M	Tutty color	None	3
Video clips	Video 5	Video 3	Video 1	Video 2	Video 4	Groups
User 19	Tutty color	M	None	Tutty color	None	
User 20	None	Tutty color	M	None	M	
User 21	M	None	Tutty color	M	Tutty color	
Video clips	Video 4	Video 3	Video 2	Video 1	Video 5	
User 22	None	M	None	Tutty color	M	
User 23	M	Tutty color	M	None	Tutty color	
User 24	Tutty color	None	Tutty color	M	None	4

Fig. 12. Organization of the mulsemedia subjective experiment.

APPENDIX I

Figure 12 shows the 24 different combinations of mulsemedia effects and video associated to each user. In the figure, *None* indicates scenario 1 - no multi-sensory effect was present during the video playout; *M* indicates scenario 2 in which all three multi-sensory effects are present and the olfaction scent matches the video content; *Tutty color* represents scenario 3, in which all three multi-sensory effects occur, but the scent diffused is always the same *Tutty color*, regardless of the olfaction stimulus suggested by the video clip's content.

APPENDIX II

Table III presents the questions employed in the post-tests, designed specifically to test learning outcome following exposure to the five multi-sensory clips: *Solar*, *Kinetic*, *Hydro*, *Climate Change*, and *Renewable Energy*.

TABLE III
POST-TEST QUESTIONS

Video 1: *Solar*

No	Question	Bloom Taxonomy Type	Answer
1	Cell phone towers generate high electromagnetic fields. True or False?	REMEMBERING	TRUE
2	TV signals are not examples of electromagnetic field. True or False?	REMEMBERING	FALSE
3	What can be powered through wireless and mobile communications energy harvesting?	APPLYING	CELL PHONES
4	Name an industry which may be resistant to these kinds of energy harvesting?	APPLYING	Marked 0 - no answer/don't know; 1 - attempt made; 2 - reasonable answer
5	Which do you think will be more useful - tv signals, wireless radio networks, cell phone towers? Why?	EVALUATING	Marked 0 - no answer/don't know; 1 - attempt made; 2 - reasonable answer
6	Which do you think is more beneficial - energy harvesting from wireless and mobile communications or human based energy harvesting. Why?	EVALUATING	Marked 0 - no answer/don't know; 1 - attempt made; 2 - reasonable answer

Video 2: *Kinetic*

No	Question	Bloom Taxonomy Type	Answer
1	A mobile device may be charged using the vibration inside a vehicle. True or False?	REMEMBERING	TRUE
2	Charging a mobile device using the spinning mechanism described in the video is an example of kinetic or mechanical energy harvesting?	REMEMBERING	KINETIC
3	Wind energy can be used in the context of vehicular networks for powering road-side units. True or False?	APPLYING	TRUE
4	Wind energy is not appropriate for mobile charging. Why is this?	APPLYING	Marked 0 - no answer/don't know; 1 - attempt made; 2 - reasonable answer
5	Which do you think is more beneficial - kinetic or mechanical energy harvesting. Why?	EVALUATING	Marked 0 - no answer/don't know; 1 - attempt made; 2 - reasonable answer
6	Why do you think there is not more widespread adoption of wind power globally?	EVALUATING	Marked 0 - no answer/don't know; 1 - attempt made; 2 - reasonable answer

Video 3: *Hydro*

No	Question	Bloom Taxonomy Type	Answer
1	Hydro-based energy harvesting is often used to power sensors for environmental applications. True or False?	REMEMBERING	TRUE
2	In the context of roadside units, hydro-based energy is often used to assist vehicular networks. True or False?	REMEMBERING	FALSE
3	What type of energy harvesting is used to in photovoltaic power stations?	APPLYING	SOLAR
4	Name three other devices which could be powered using small scale solar panels?	APPLYING	PHONES; WATCHES; CARS
5	Name a regional factor that would affect a nations choice to use these types of harvesting?	EVALUATING	Marked 0 - no answer/don't know; 1 - attempt made; 2 - reasonable answer
6	Why do you think there is not more widespread adoption of solar panels as a consumer product?	EVALUATING	Marked 0 - no answer/don't know; 1 - attempt made; 2 - reasonable answer

Video 4: *Climate Change*

No	Question	Bloom Taxonomy Type	Answer
1	Carbon dioxide, oxygen and methane are gases which increase the greenhouse effect. True or False?	REMEMBERING	FALSE
2	Chlorofluorocarbons are considered to assist in raising the global temperature. True or False?	REMEMBERING	TRUE
3	Under what conditions do ozone particles increase to cause smog?	APPLYING	HIGHER TEMPERATURES
4	List three ways by which human physical health is impacted due to climate change	APPLYING	FOOD; STORMS; HEALTH
5	Climate change is a vicious circle. Why?	EVALUATING	Marked 0 - no answer/don't know; 1 - attempt made; 2 - reasonable answer
6	How should these changes affect the way humans grow and consider food?	EVALUATING	Marked 0 - no answer/don't know; 1 - attempt made; 2 - reasonable answer

Video 5: *Renewable Energy*

No	Question	Bloom Taxonomy Type	Answer
1	Geothermal sources create no air pollution emissions. True or False?	REMEMBERING	FALSE
2	Hydro-electric sources create no air pollution emissions. True or False?	REMEMBERING	TRUE
3	What percentage of total energy consumption was indicated as being from renewable sources?	APPLYING	10
4	Renewable sources do cause minimal greenhouse gas emissions. How?	APPLYING	INDIRECT: PARTS AND MAINTENANCE
5	Renewable energy may do harm in the short term. Discuss.	EVALUATING	Marked 0 - no answer/don't know; 1 - attempt made; 2 - reasonable answer
6	Why do you think governments are slow to implement renewable energy on a large scale?	EVALUATING	Marked 0 - no answer/don't know; 1 - attempt made; 2 - reasonable answer

REFERENCES

[1] Cisco, "Cisco visual networking index complete traffic forecast (2017-2022)," *Cisco Public Inf.*, 2018.

[2] PTC, "Getting started with industrial augmented reality solutions," White Paper. [Online], Available: https://www.ptc.com/en/resources/augmented-reality/white-paper/-/media/AB6BF03F3DDE4BD3B71950-74A203FAFA.ashx

[3] N. Murray, B. Lee, Y. Qiao, and G.-M. Muntean, "Olfaction-enhanced multimedia: A survey of application domains, displays, and research challenges," *ACM Comput. Surveys*, vol. 48, no. 4, p. 56, 2016.

[4] N. Ranasinghe *et al.*, "Vocktail: A virtual cocktail for pairing digital taste, smell, and color sensations," in *Proc. ACM Multimedia Conf., New York, 11391147*, 2017.

[5] G. Ghinea and J. P. Thomas, "Quality of perception: User quality of service in multimedia presentations," *IEEE Trans. Multimedia*, vol. 7, no. 4, pp. 786–789, Aug. 2005.

[6] L. Zou, T. Bi, and G.-M. Muntean, "A dash-based adaptive multiple sensorial content delivery solution for improved user quality of experience," *IEEE Access*, vol. 7, pp. 89 172–89 187, 2019.

[7] T. Bi *et al.*, "A dash-based mulsemedia adaptive delivery solution," in *Proc. 10th Int. Workshop Immersive Mixed Virtual Environ. Syst.* ACM, 2018, pp. 1–6.

[8] G. Ghinea, C. Timmerer, W. Lin, and S. R. Gulliver, “Mulsemedia: State of the art, perspectives, and challenges,” *ACM Trans. Multimedia Comput., Commun., Appl.*, vol. 11, no. 1 s, p. 17, 2014.

[9] J. J. Van Merriënboer and L. Kester, “The four-component instructional design model: Multimedia principles in environments for complex learning,” *The Cambridge handbook of multimedia learning*, 2014, pp. 71–93.

[10] G. Ghinea and O. A. Ademoye, “Perceived synchronization of olfactory multimedia,” *IEEE Trans. Syst., Man, Cybern.-Part A: Syst. Humans*, vol. 40, no. 4, pp. 657–663, Jul. 2010.

[11] A. Covaci, L. Zou, I. Tal, G.-M. Muntean, and G. Ghinea, “Is multimedia multisensorial?-A review of mulsemedia systems,” *ACM Comput. Surveys*, vol. 51, no. 5, p. 91, 2018.

[12] P. Ayres, “State-of-the-art research into multimedia learning: A commentary on mayer’s handbook of multimedia learning,” *Appl. Cogn. Psychol.*, vol. 29, no. 4, pp. 631–636, 2015.

[13] M. Ischer *et al.*, “How incorporation of scents could enhance immersive virtual experiences,” *Frontiers psychol.*, vol. 5, p. 736, 2014.

[14] S. Rasool and A. Sourin, “Real-time haptic interaction with RGBD video streams,” *Vis. Comput.*, vol. 32, no. 10, pp. 1311–1321, 2016.

[15] E. Richard, A. Tijou, P. Richard, and J.-L. Ferrier, “Multi-modal virtual environments for education with haptic and olfactory feedback,” *Virtual Reality*, vol. 10, no. 3–4, pp. 207–225, 2006.

[16] A. Tijou, E. Richard, and P. Richard, “Using olfactive virtual environments for learning organic molecules,” in *Proc. Int. Conf. Technol. E-Learning Digit. Entertainment*. Springer, 2006, pp. 1223–1233.

[17] L. Zou *et al.*, “Can multisensorial media improve learner experience?” in *Proc. 8th ACM Multimedia Syst. Conf.*, 2017, pp. 315–320.

[18] B. G. Witmer and M. J. Singer, “Measuring presence in virtual environments: A presence questionnaire,” *Presence*, vol. 7, no. 3, pp. 225–240, 1998.

[19] S. V. Shannon, “Using metacognitive strategies and learning styles to create self-directed learners,” *Inst. Learn. Styles J.*, vol. 1, no. 1, pp. 14–28, 2008.

[20] H. Q. Dinh, N. Walker, L. F. Hodges, C. Song, and A. Kobayashi, “Evaluating the importance of multi-sensory input on memory and the sense of presence in virtual environments,” in *Proc. IEEE Virtual Reality (Cat. No. 99CB36316)*. 1999, pp. 222–228.

[21] G. Ghinea and O. Ademoye, “The sweet smell of success: Enhancing multimedia applications with olfaction,” *ACM Trans. Multimedia Comput., Commun., Appl.*, vol. 8, no. 1, pp. 1–17, 2012.

[22] G. Von Békésy, “Olfactory analogue to directional hearing,” *J. Appl. Physiol.*, vol. 19, no. 3, pp. 369–373, 1964.

[23] J. S. Warm, W. N. Dember, and R. Parasuraman, “Effects of olfactory stimulation on performance and stress,” *J. Soc. Cosmetic Chemists*, vol. 42, no. 3, pp. 199–210, 1991.

[24] R. A. Baron, “Environmentally induced positive affect: Its impact on self-efficacy, task performance, negotiation, and conflict 1,” *J. Appl.Social Psychol.*, vol. 20, no. 5, pp. 368–384, 1990.

[25] J. Degel and E. P. Köster, “Odors: Implicit memory and performance effects,” *Chem. Senses*, vol. 24, no. 3, pp. 317–325, 1999.

[26] N. Murray, O. A. Ademoye, G. Ghinea, and G.-M. Muntean, “A tutorial for olfaction-based multisensorial media application design and evaluation,” *ACM Comput. Surveys*, vol. 50, no. 5, pp. 1–30, 2017.

[27] J. C. Verlinden *et al.*, “Enhancement of presence in a virtual sailing environment through localized wind simulation,” *Procedia Eng.*, vol. 60, pp. 435–441, 2013.

[28] Z. Yuan, G. Ghinea, and G.-M. Muntean, “Beyond multimedia adaptation: Quality of experience-aware multi-sensorial media delivery,” *IEEE Trans. Multimedia*, vol. 17, no. 1, pp. 104–117, Jan. 2015.

[29] T. Bi *et al.*, “A study of learning experience with a dash-based multimedia delivery system,” in *Proc. EDULEARN Conf., Palma de Mallorca, Spain*, 2018.

[30] T. Bi, F. Silva, G. Ghinea, and G.-M. Muntean, “Improving learning experience by employing dash-based mulsemedia delivery,” in *Proc. IEEE Games, Entertainment, Media Conf.* 2018, pp. 1–9.

[31] N. Nurseitov, M. Paulson, C. Reynolds, and R abd Izurieta, “Comparison of JSON and XML data interchange formats: A case study,” *Comput. Appl. Industry Eng.*, pp. 157–162, 2009.

[32] Z. Yuan, T. Bi, G.-M. Muntean, and G. Ghinea, “Perceived synchronization of mulsemedia services,” *IEEE Trans. Multimedia*, vol. 17, no. 7, pp. 957–966, Jul. 2015.

[33] T. Bi, Z. Yuan, R. Trestian, and G.-M. Muntean, “URAN: Utility-based reputation-oriented access network selection strategy for hetnets,” in *Proc. 2015 IEEE Int. Symp. Broadband Multimedia Syst. and Broadcast.* 2015, pp. 1–6.

[34] K. Mahmud, M. Inoue, H. Murakami, M. Hasegawa, and H. Morikawa, “Measurement and usage of power consumption parameters of wireless interfaces in energy-aware multi-service mobile terminals,” in *Proc. IEEE 15th Int. Symp. Pers., Indoor Mobile Radio Commun. (Cat. No. 04TH8754)*, vol. 2, Sep. 2004, pp. 1090–1094 Vol.2.

[35] B. S. Bloom *et al.*, “Taxonomy of educational objectives. vol. 1: Cognitive domain,” *New York: McKay*, 1956.

[36] L. W. Anderson and D. R. Krathwohl, “A taxonomy for learning, teaching and assessing: A revision of blooms taxonomy of educational objectives,” *New York: Longman*, 2001.

[37] N. Athanassiou, J. M. McNett, and C. Harvey, “Critical thinking in the management classroom: Bloom’s taxonomy as a learning tool,” *J. Manage. Educ.*, pp. 533–555, 2003.

[38] H. M. Cannon and A. H. Feinstein, “Bloom beyond bloom: Using the revised taxonomy to develop experiential learning strategies,” *Developments Bus. Simul. Experiential Learn.*, 2014.

[39] K. R. Butcher, “The multimedia principle,” *The Cambridge handbook of multimedia learning*, vol. 2, 2014, pp. 174–205.

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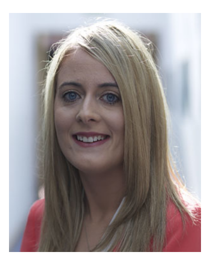

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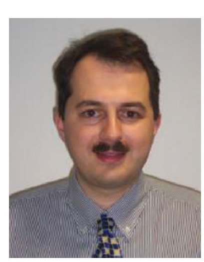

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