Computer and Materials Sciences convergence for the creation of technology based learning resources and new curriculum developments

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***Abstract*—In this Innovative Practice work in progress paper, we discuss the convergence of two engineering disciplines (computer and materials sciences) for the co-creation of technology-based learning resources, achieved through transdisciplinary student-staff partnerships. The partnerships are made of producers (computer science students and staff) and clients (materials science students and staff) working together towards the creation of Augmented Reality (AR) and Virtual Reality (VR) interactive simulations that are made by students for students. The student-staff partnership was achieved through a careful balance of roles, knowledge, and experience. We achieved an equal partnership through mixing two very disparate disciplines that share little knowledge through the curriculum. We have observed multi-level benefits through the partnership: the student-producers develop technical and professional skills that allow them to competently address scientific and societal challenges. The student-clients acquire domain expertise needed to advise and guide the producers and manage projects. This is also a unique opportunity for staff since they experience learning from students, and the process during the development and testing of ideas can enhance their teaching practice and open new avenues for curriculum development.**

Keywords—co-creation, transdisciplinarity, student-staff partnerships, learning resources

I. Introduction

Convergence is a term that was originally defined as the 'integration of knowledge, methods, and expertise from different disciplines and forming novel frameworks to catalyze scientific discovery and innovation' [1]. This definition includes the different actors and stakeholders that participate in the process, contributing with their different areas of expertise and background knowledge. The integration of different disciplines brings the challenge of creating common language and tools necessary for tackling scientific and societal challenges that exist at the interfaces of multiple fields [2]. In recent years, convergence has transitioned into the educational arena and the original concept has been generalized to cover both research and education. For example, convergence has played a key role in the development of engineering fields at the intersection with biology, medicine and computer science and has been responsible for the development of areas of education and research such as biochemical engineering, biomedicine, synthetic biology, nanotechnology and soft robotics, to mention a few.

Virtual Reality (VR) and Augmented Reality (AR) have been signposted as key technologies for shifting educational practices. For several years, these technologies were used by a small minority of tech-savvy academics and students but since the arrival of the COVID-19 pandemic in 2020, there has been a surge on the development and use of classroom resources that are 'born digital' either online or using virtual environments. A few examples have been highlighted as the gold standards for enabling a wider remote access to classrooms, with the best examples built as open educational resources freely available to any student and on any device [1]. With the new global challenges, we are at a crossroads, moving from 'physical' to 'virtual' classrooms where learning takes place at different times, opening opportunities for enhancing visualization, interaction and access to resources and spaces that otherwise were not possible.

In Materials Science and Engineering, the use of computer-based models has become wide-spread, particularly in atomistic and molecular 2D simulations [3]. These models contribute both in the teaching and learning of atoms and molecule formation as well as quantum predictions of formation of molecules in research of existing and novel materials. Immersive technologies and 3D simulations (e.g. VR and AR) can further help students understand theoretical concepts more easily and keep them engaged in learning. AR and VR have already been shown to be potentially very useful when teaching about science and engineering topics that are difficult to experience due to being abstract or invisible, or when non-availability of equipment and space, or distance, are a limitation [4,5].

The application of convergence in education and the emergence of advanced learning technologies such as VR and AR set the context for the project described in this paper. Although our journey started before the pandemic, it has become evident that the tools that we are developing are becoming more and more necessary in the engineering classroom. In this project, we propose to shift from the teacher-led traditional methods for developing classroom resources to transdisciplinary partnerships where students and academics collaborate in the design and implementation of teaching material. Student-staff partnerships for co-creation in learning and teaching have gained momentum in the last few years as a successful model for empowering learners and share the decision-making process of learning and teaching [6,7]. In this paper, we discuss the convergence of computer and materials science using VR and AR for the creation of learning resources. We examine the idea of partnerships as a convergence of two different engineering themes – materials science and computer engineering; at the junction of VR and AR with education under the umbrella of two distinctive learning actors: students and staff. The fusion of these elements results in the creation of learning resources and

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development of teaching and learning practices which have a positive impact on the learning community.

II. Transdisciplinary Co-creation for Achieving Convergence

Collaborations between academics from different disciplines or between academic staff and students are not new ideas but are at the core of the definition of convergence. Transdisciplinarity is considered as the ideal model that transcends the natural boundaries of disciplines and as such, we use this term to conceptualize this project.

In this project, we have used co-creation as an approach that enables equity in the participation of all the members of the partnership. Figure 1 shows a representative framework for the partnership. Co-creation gives students and staff the same level of choice and ownership, focusing on the product that can be achieved through the collaboration. This ensures that all partners have shared responsibilities and profit from the interaction. Due to the transdisciplinarity of the project, staff become learners at the same level as students, since they are not experts in all the areas required for delivering the outcomes.

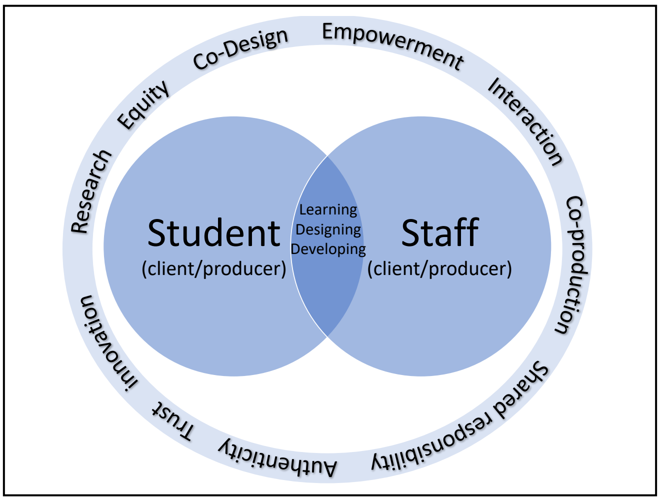

Figure 1. The co-creation partnership model

The inner diagram of the framework shows the equal contribution of staff and students as clients or producers in the design, development, and delivery of learning. The outer circle outlines the values which underpin the partnership; including empowerment, where all parties have distributed powers to promote a healthy dynamic; equity and inclusivity, allowing to challenge barriers that prevent engagement and authenticity for all parties to invest in a meaningful and credible way in the relationship. This enables trust in the interactions and shared responsibility in the delivery of innovations. This results in a day-to-day relationship that is collegial, friendly, and creative.

The framework was implemented in the project through roles definition, sharing responsibility amongst all members and regular team meetings. The roles of the partners were defined as clients or producers (Figure 2). The team from Materials engineering became the clients and the Computer engineering team became the producers. The teams are based across different countries although we are all members of the Queen Mary University of London (QMUL) transnational educational programmes in China. The team at the Queen Mary Engineering School, Northwestern Polytechnical University (QMES-NPU) is based in Xi'an and is expert on Materials Science and Engineering. The team at the QMUL School of Electronic Engineering and Computer Science and at the International School of the Beijing University of Posts and Telecommunications (BUPT) in Beijing is expert in Multimedia Engineering. The transnational programmes are collaboratively designed to equip Chinese students with a combination of the best aspects of two different education systems (from the UK and from China).

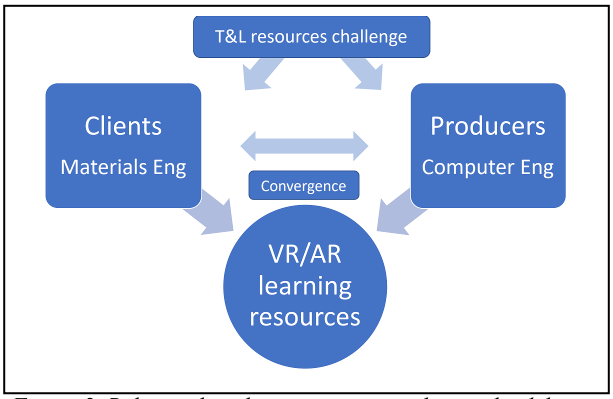

Figure 2. Relationships between partners during the delivery of the learning resources

We have worked in this project since Autumn 2019. Students from the senior years are engaged through volunteering (QMES-NPU) or through their final dissertation project (QMUL-BUPT). Students are the ideal partners in the development of learning resources since they bring their own perspectives, understand what may be easy or difficult to learn, and help academics identify common misconceptions and incorrect assumptions they may have about students' needs and prior knowledge. The team of clients identified the needs and requirements for the VR/AR simulations, provided data and guidelines and tested and provided feedback on prototypes. The producers team designed the VR and AR prototypes and identified challenges and solutions for translating knowledge into applications. All the partners participated in the development of an approach to deploy the evaluation of prototypes using multi-media and surveys. This will be discussed later in this paper.

Over the duration of the project, one member of staff and 3 students from QMES have acted as clients and one member of staff and 5 students of QMUL-BUPT have participated as producers.

III. Using Student-Staff Partnerships for Developing VR and AR Learning Resources

In the development of VR and AR learning resources, we had different compositions of the teams: i) a partnership with an equal number of staff and students; and ii) a partnership with a different number of staff and students. The rationale for this distinction was organic; as the project evolved over time, there were different numbers of students interested in taking part in activities and hence, the number of members changed.

A. A partnership with equal number of participants

In the first part of this project, we focused on the production of learning resources for one laboratory experiment in Materials engineering (Rockwell hardness test) using VR and one visualisation concept (light diffraction by molecules) using AR. For these tasks, we recruited 2 students as clients and 2 students as producers, making the number of partners equal. Students from each area worked in pairs and with the academic staff through the articulation of the problem to the evaluation of the products. They have also participated in other outputs of the project such as reports, videos, talks and publications, obtaining all the benefits from the partnership, from the learning and design process, decision making, through to dissemination of outputs. The details of the AR prototype for the study of light transmission through materials have been published elsewhere [8].

In the case of the VR prototype, the simulation was built in 3D Max using an Oculus Rift VR headset [9] and a Leap Motion sensor [10]. The details of setting the simulation were discussed in a previous publication [8] and are summarized here. The Rockwell hardness test is used routinely in Materials engineering to measure metal hardness by estimating the permanent depth of indentation produced by a force or load applied on an indenter of the tester on the surface of a metal. The experimental process was translated into a VR simulation by creating models of the apparatus and samples in 3D Max and placing this in a virtual laboratory environment developed in Unity 3D (Figure 3).

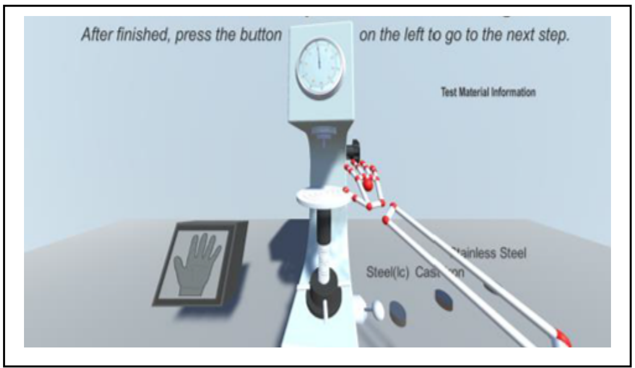

Figure 3. Rendering of Rockwell hardness VR simulation in Unity 3D showing some UI objects

The VR prototype was evaluated using a survey deployed to 75 Year 3 undergraduate students and showed that 80% of students believe a VR application can improve their understanding of materials science in general. Over 85% of the students think VR can enhance their learning experience, as a faster and easier way to acquire knowledge.

B. Partnerships with unequal number of participants

In the second part of the project, there were 1 student and 1 academic in the clients' team and 3 students and 1 academic in the producers' team. This caused an imbalance since the levels of experience were different and the client team took the roles of advisor as well as user. Three simulations were developed: visualization of crystal dislocation and materials tensile test using VR and fractography of materials using AR. The tensile test on VR was developed using Blender and Unity 3D coupled with an Oculus Rift headset [9]. The AR experience was developed as an Android application for mobile phones using 3D Max and Vuforia [11] for implementing object recognition and real-time object tracking. We will focus here on the findings for the VR experience of crystal dislocation, since it was developed with quick and easy deployment in mind, using Android mobile phones and a cardboard headset.

The dislocation of atoms in a crystalline structure gives materials their ability to resist a force. At atomic level, atoms are displaced during the breaking and making of bonds, allowing the retention of the overall crystal structure, and creating defects in the process. The imperfections that appear are responsible for properties of materials such as plastic deformation and its understanding is fundamental in the strengthening of metals [12]. This is an abstract concept difficult to understand but simple to represent in a VR simulation. Figure 4 shows a scene from the crystal dislocation VR application. Due to the simplicity of the design, the user operates the simulation by staring at areas of the screen that allow to control the process, eliminating the need of a motion sensor and making the simulation ready to use by any user with an Android mobile phone and a cheap cardboard headset.

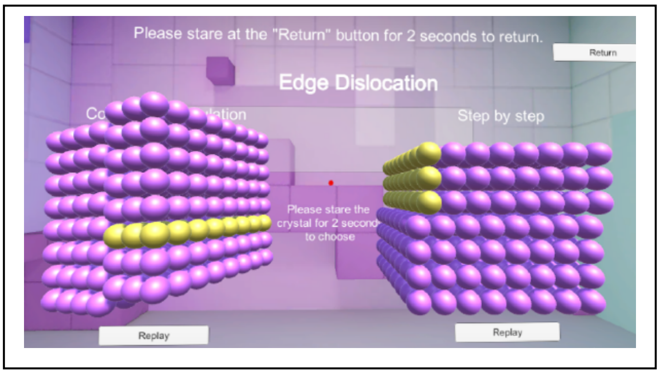

Figure 4. Simulation scene of the VR crystal dislocation application

The VR application was evaluated using results from survey responses of 20 from Y1 – Y3 undergraduate students with varying degrees of knowledge in this area, from very little to excellent knowledge. 77% of students agreed that the simulation is suitable for self-learning this concept, with 88% of responses indicating that the simulated process is easy to understand. However, 82% of the users found difficult to interact with the simulation using head motion and gaze. Globally, the success of the testing process indicated that using a cardboard headset is an adequate option for deploying classroom simulations. Above all, the highly positive results from the evaluation of these projects demonstrated the importance of diversifying the learning experience by using these technologies.

IV. Implementing Convergence in the Student-Staff Partnerships

In this project, we experience convergence of two areas of engineering and the merging of partners with different positions of authority. For a project to become truly interdisciplinary it is necessary to reach a common framework to solve the problem in question. We achieved this by setting clear expectations from the start of the project with a general objective of delivering simulations for teaching Materials science. There is a wide range of options for the content and type of simulations available from a Materials Engineering perspective and these options were thoroughly explored as a team. The decisions of the areas selected for development were then collectively made based on the understanding of the technical difficulties (e.g. software and hardware availability), time needed for completing a product, methods for deployment in the classroom, availability of data for creating the simulations and acceptance criteria both of software and hardware; since a key performance indicator was that the product fulfills the demands of the learning community. This required that all partners (students and staff) understood the limitations and challenges of each area and learn from each other technical details that were beyond their traditional areas of knowledge. A similar behavior was observed when exposing computer science students to experiential learning in a convergence with evolutionary biology [13]. However, in this project, we achieved a balance of roles in the partnerships since all partners acted as learners or experts at some point during the project, placing all the participants at the same level of power and empowering partners through the delivery of the project.

The students who participated in the equal number of partners experience through self-reflection reported a high level of satisfaction since they were empowered to lead an area (clients as experts) or select an area for development (producers as experts). They also recognized the importance and impact of the work they developed on their learning community of peers, and the transferable skills they acquired through the experience. From a staff viewpoint, this experience provided opportunities for development in new areas, to adopt novel methodologies for seeking solutions, and demonstrated the advantages of merging areas of engineering for the advancement of learning.

The experience in the unequal number of partners partnership was very productive but at the expense of student interactions. The student-producers were pushed beyond their area of expertise since they had to learn a lot of the fundamentals of Materials Engineering on their own in order to embed this knowledge into the simulations. This has the benefit of strengthening students' skills and ability to expand their expertise and problem-solving approach. However, it was difficult for the students to balance the power relationships since they always perceived the academic staff as advisors rather than partners.

An added benefit of transdisciplinary partnerships such as the one described in the paper is to bring together academics in search of opportunities for grounding the students' technical knowledge in meaningful and professional activities, and academics with educational needs and ideas about how to use the technology but no means to implement these ideas. Through this project, the computer science academic was able to test and develop new activities, enriching the computer graphics curriculum to truly encompass technical, creative, and professional skills. A new course on 3D Graphics for AR and VR is under development, drawing directly from some of the lessons learned in the partnerships, through observing how the students approached the problems at hand, the challenges they faced and the solutions that most spontaneously came to their imagination.

V. Conclusions

We have demonstrated here the convergence of Materials and Computer Engineering for the development of classroom resources through a partnership model that ensures equity in the contributions from the different parties involved. The key to success of the approach used in this project relies on clear and common goals as well as a willingness of partners to become experts or learners when required, resulting in meaningful interactions for the delivery of the project.

Although unbalanced partnerships can also be productive, in the future it is important to ensure that partnerships are balanced, enhancing the sense of community and providing a richer experience to all participants.

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