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Development of a Cost-Effective Kit for an International Learning Experience in the Context of Generative Artificial Intelligence

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Abstract

One of the most common causes of school dropout is the lack of motivation due to academic strategies. This has an impact on their personal lives, as well as on their quality of life, opportunity taking and mental health.

This paper presents an interactive learning tool that complements the lessons of the school syllabus, developed through a research collaboration between the University of Sheffield, England and Tecnologico de Monterrey, Mexico. The research promotes the responsible and ethical use of Augmented Reality and Artificial Intelligence. Aligned with the 2030 Agenda containing the Sustainable Development Goals presented by the UN in 2015, this work directly contributes to Goal four (Quality Education), Goal ten (Reduced Inequalities), and Goal twelve (Responsible Consumption and Production).

The product consists of low-cost 3D assembling models made with layers of sustainable and recycled materials. By incorporating these engaging teaching tools, the project demonstrates a commitment to responsible resource use and environmental impact mitigation, levering the versality and global accessibility of laser cutting technology. This approach allows for the customization of models to meet the specific needs of different groups, such as students at various academic levels or disabled students with special and diverse learning needs, making them valuable for cognitive skill development.

Additionally, a digital platform with Augmented Reality and Artificial Intelligence has been developed to complement the physical models. This interactive system is useful for teaching, as it enhances hands-on and intercultural engineering education.

Finally, the implementation of this learning tool is carried out in an industry & steelmaking history museum and a primary school in North of England. In both cases, the activity is the same, children experience AR and AI tools to manufacture the Chichén Itzá pyramid.

Introduction

One of the most common causes that influences the intention to drop out of school is the lack of motivation [1]. Research has shown that students bear greater risk of leaving school when they become less engaged in learning activities [2]. This has a negative impact on their mental health and personal lives.

The use of interactive systems in classrooms contributes to students' motivation [3-5]. In [3], LEGO Education WeDo is used to help students begin building, coding and programming 3D models. Thus, students are encouraged to learn by doing, aiming to support student engagement. Moreover, in [4], spatial tasks, exercises, and assessments are implemented as professional development activities that might enhance students' spatial ability. The development of fabricator competency for engineering students is presented through different key components such as in [5]. Hence, approaches to guiding learning through fabrication are identified based on students' knowledge, skills, and attitudes. While these assessments might contribute to achieving learning objectives, the development of thinking, problem-solving skills, and student motivation should be explored as an extracurricular activity rather than an assignment that takes place in a classroom environment.

Augmented reality (AR) is a technology that overlays virtual objects in the real-world environment, which enhances users' engagement [6]. This technology has been applied to encourage critical thinking in learners of different ages [7-9]. Through the Assemblr Edu platform, it is shown in [7], that English writing skills are improved. Similarly, in [8], AR technology is used to facilitate collaborative learning in science education, while in [9], it is implemented to teach the human skeletal anatomy. Thus, visualization and interaction of abstract scientific concepts are carried out. In this paper, an interactive learning tool that complements the lessons of the school syllabus is presented. It is an outcome of a research collaboration between the University of Sheffield, England and Tecnologico de Monterrey, Mexico, and it has been implemented in different environments in England, which contributes to being evaluated from different perspectives [10]. The research work uses AR technology to further users' learning experience. Additionally, responsible and ethical applications of Artificial Intelligence (AI) are performed.

Literature Review

Quality Education

Based on the Sustainable Development Goals (SDG) of the 2030 Agenda presented by the United Nations (UN) in 2015, the SDG 4 establishes: "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all". Here, the development of opportunities across all phases of education – pre-primary, primary, secondary, vocational, higher and adult education are encouraged [11]. Nevertheless, resource constraints present severe limitations for education, thus, quality challenges at the primary and secondary levels tend to lead to a high proportion of under-prepared students entering university [12]. Therefore, to warranty equitable quality education, the design of learning tools must consider critical issues faced in low- and middle-income countries.

Additive Manufacturing in Education

Additive Manufacturing (AM), which collectively refers to methods of bottom-up object creation by layer-by-layer material joining [13], expands the design space for complex objects.

Although AM has been applied in classrooms as part of manufacturing curriculum in engineering education [14-16], the implementation of this technique on groups of early-age students is fairly well-known by experts in the field. In [17] presents the design and creation of supporting teaching materials using AM for elementary and first-year engineering students. In this case, 3D printed pieces are a learning tool, complementing traditional approaches such as technical information cards or artworks of museums, which can be costly.

Technology is playing a significant role in promoting and establishing a healthy engineering education ecosystem in schools and universities. Indeed, current AM technologies enable the exploration of recycled materials [18]. Hence, a motivating and sustainable learning tool can be designed for teaching.

Materials and Methods

Even though Science, Technology, Engineering, and Mathematics (STEM) offers an interdisciplinary perspective with a positive contribution to students' creativity, achievement, motivation, critical thinking, problem solving, and higher order skills [19], traditional type classrooms often do not encourage students' curiosity in these disciplines [20].

The present research work is the culmination of one year of a Worldwide Universities Network (WUN) - funded project, and it is based on an international collaboration at two large universities: the University of Sheffield and Tecnologico de Monterrey. The work produced promotes STEM education through the implementation of a sustainable AM workshop named "Boosting Mexican Culture Using Additive Manufacturing Technology: A Sustainable Hands-on Experience". Primary school-age students were invited to take part in this workshop to design and build cost-effective 3D assembling models made with cardboard sheets. Additionally, learners engaged with AR and AI tools linked to the cardboard model, providing further context to the activity and situating the cultural background of the model. The workshop can be carried out in a school classroom environment or as an extracurricular activity.

As shown in Figure 1, the methodology followed in this research is composed of three main stages, such as, Model selection, Implementation and Data analysis, summarized as follows:

Model selection. This stage was carried out during a series of meetings between collaborators and ahead of the workshop. We (or the ambassador) selected a culturally relevant design to promote an intercultural perspective of additive manufacturing through a historic building. The next steps involved prototyping the laser cut, obtaining the model blueprints, optimizing the cutting material and laser cutting of the selected model to optimize the time invested in the activity.

Then, in flow A1, to validate the prototype the ambassador must determine if the model is easy to assemble, verify the quality of the laser cut, measure the cutting time, and determine the quantity of required material.

Therefore, in flow A2, to validate the learning quality, the ambassador must verify if the model covers the main topics taught in the workshop, if the model facilitates the understanding of complex topics of additive manufacture and if it enables interactive learning. Thus, large-scale production can be carried out.

Implementation. Here, the professor introduces the main objective of the workshop. Hence, the flow "B1" allows students to relate the additive manufacture theory concepts acquired previously. Then:

- Based on the students' reasoning, in flow "B2" they associate the model elements of the kit with theory. In these activities, it is essential that participants use the necessary skills gained in the workshop. The participants are divided into teams and encouraged to work together [21].
- Using the AR and AI tool and under the supervision of the ambassador, the students can assemble their models, and flow "B3" stands to represent the knowledge acquired to connect the kit components. Here, the method increases the students' level of motivation [22] and the sense of individual responsibility for their own learning [23].
- In flow "B4", the learners prove the correct behavior of their kits.
- Hence, according to the results of the assembled prototype, flow "B5" allows students to carry out the process activities in class.
- Furthermore, the flow "B6" allows students to make some adjustments in their assembled prototypes; this, in the case of the model is not achieved due to either unexpected damage. Thus, flow "B7" allows students analyze their results to present and write the final report even though they attend the workshop remotely. Here, the student exploits the collective responsibility when working on a team [24],[25]. The method was adapted to any learning situation, such as the dual mode and face-to-face mode [26].

Data analysis. To analyze the data, educators could collect the assessments. For this task, the exploratory factor analysis (EFA) that includes items could be used.

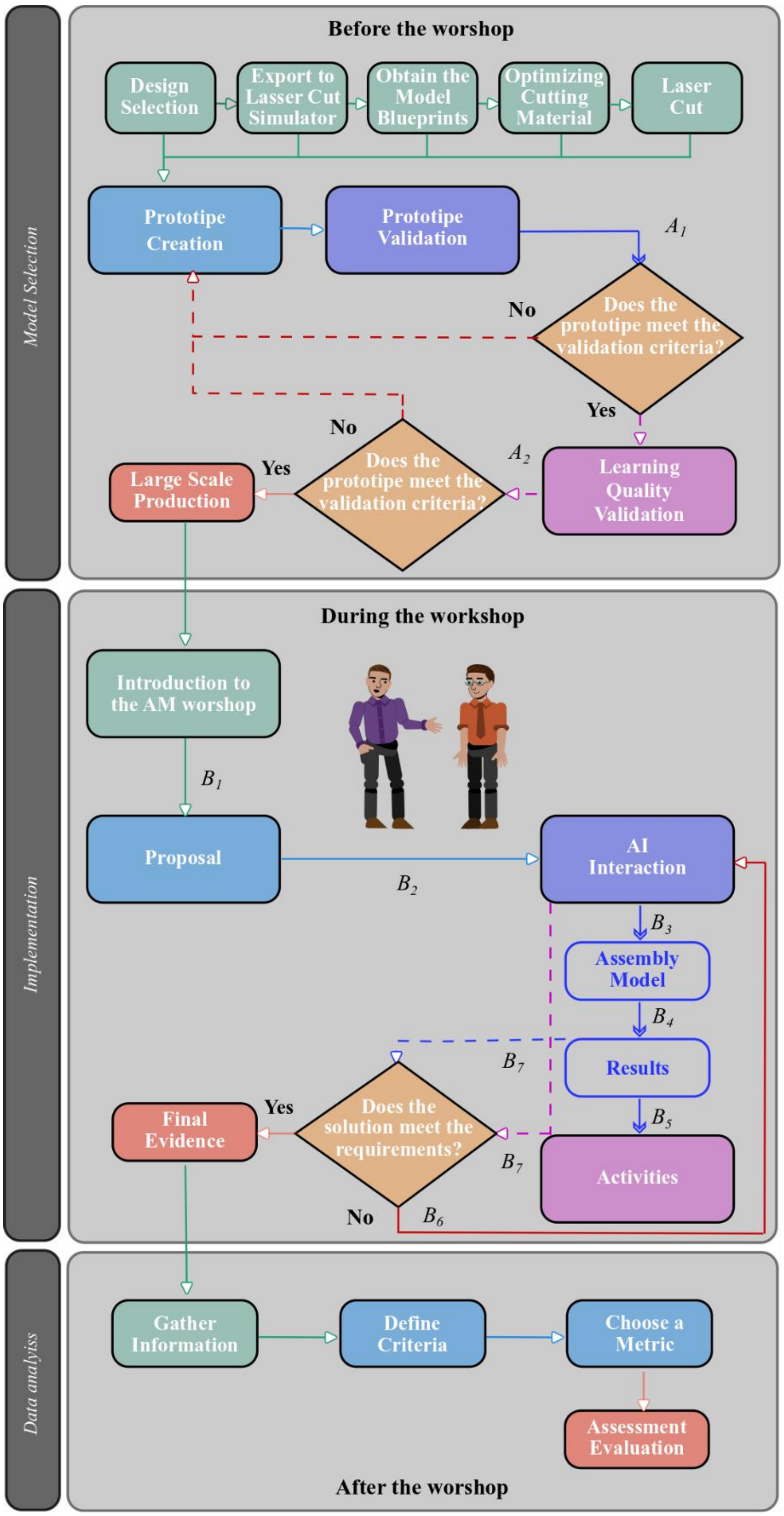
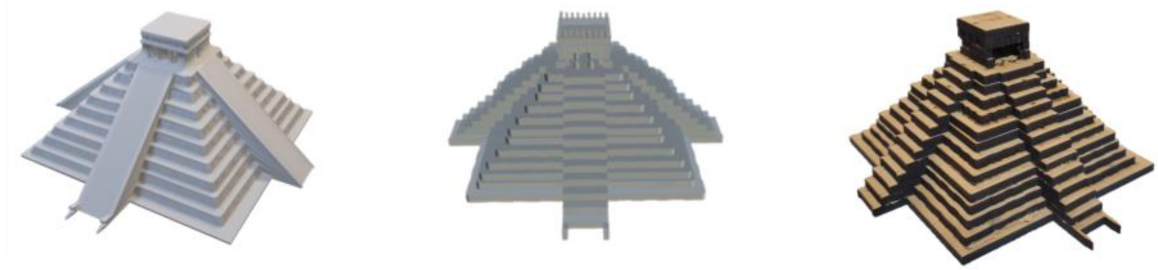


Figure 1. Methodology sustainable additive manufacturing workshop.

Results

3D Model

The model for teaching and student learning is defined according to University of Sheffield facilities. Here, Chichén Itzá pyramid is chosen as the prototype to be manufactured, Figure 2 a). Thus, the scan of the sculpture is done, and the *.stl archive is obtained, with enough resolution and detail, Figure 2 b). The dimension of the model is rescaled to 20×20 cm of base and 10 cm of height. Then, using the software Autodesk Slicer for Fusion, the archive *.dxf is created, and the model is divided into 17 layers; this, considering that it is sliced vertically with a thickness of 5 mm. Hence, the pyramid model can be built using recycled material, Figure 2 c), where the characteristic of the architecture is well identified by the learners.



a) 3D scan **b) Model slicing** **c) Cardboard model**

Figure 2. Chichén Itzá pyramid 3D model.

Figure 3 shows the model's slicing results in the blueprint. As it can be seen, each piece is labeled with a number; this, to indicate the order in which they must be stacked, from the bottom to the top. The pieces are distributed on a sheet of cardboard, which has a dimension of 61×41 cm and a thickness of 5 mm, as the layers previously defined.

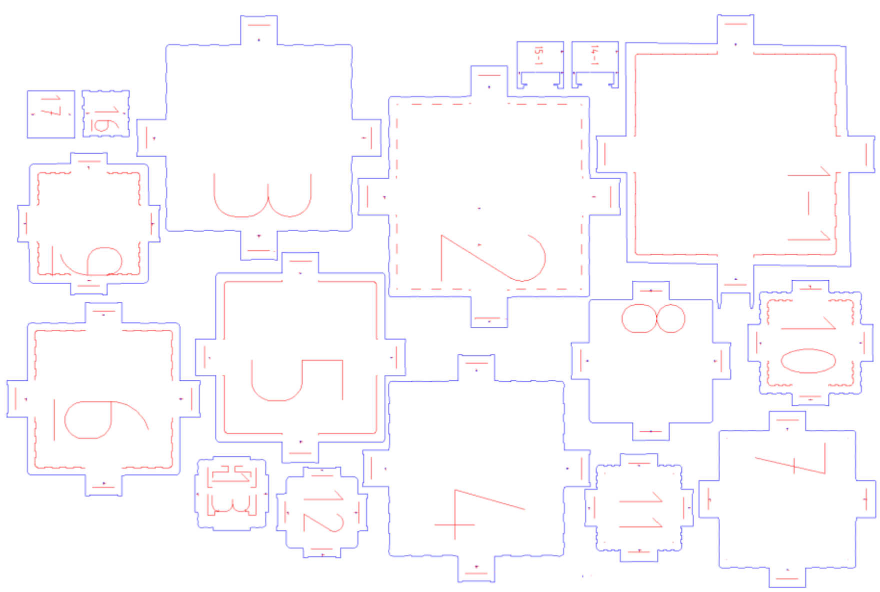


Figure 3. Layers' blueprint.

Characters and Animation

Cartoon characters of two professors are developed as digital vector models, Figure 4. The design takes into account two main aspects, the rigging and the joints. Hence, a puppet animation is performed, and different kinds of gestures and movements can be carried out.

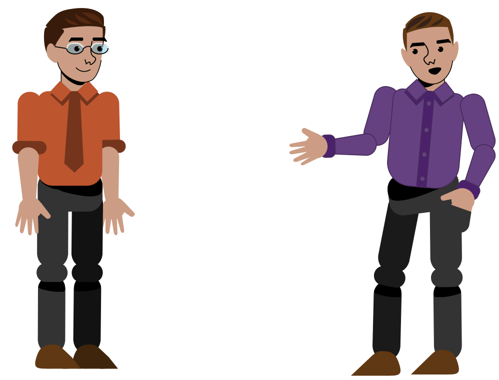


Figure 4. Animated characters (manufacturing experts and university educators).

To match a specific script telling, the characters are animated by using Adobe® After Effects and Blender. Additionally, AI is applied to identify and execute the adequate movements and gestures of the characters; thus, new animations are generated according to the dialogues. Furthermore, the voices of the characters are generated with text-to-speech (TTS) model training based on recorded audio from two manufacturing experts and university educators.

AR Experience and App Development

Building on the concept of 3D computer modeling and AI-assisted teaching, an AR experience was created. In this experience, animated representations of two animated educators appear as digital overlays realistic visuals, alongside the pyramid model built by the student. This integration of AR enables students to interact with the model of an ancient pyramid through a combination of both the digital and tangible world, while the animated characters provide an explanation of the 3D model.

To achieve this, a base design was created to support the cardboard model (Figure 5). It features a colored image of the feathered serpent, which serves as a visual marker for the program to track and trigger the AR contents, overlaying the animation onto its position.

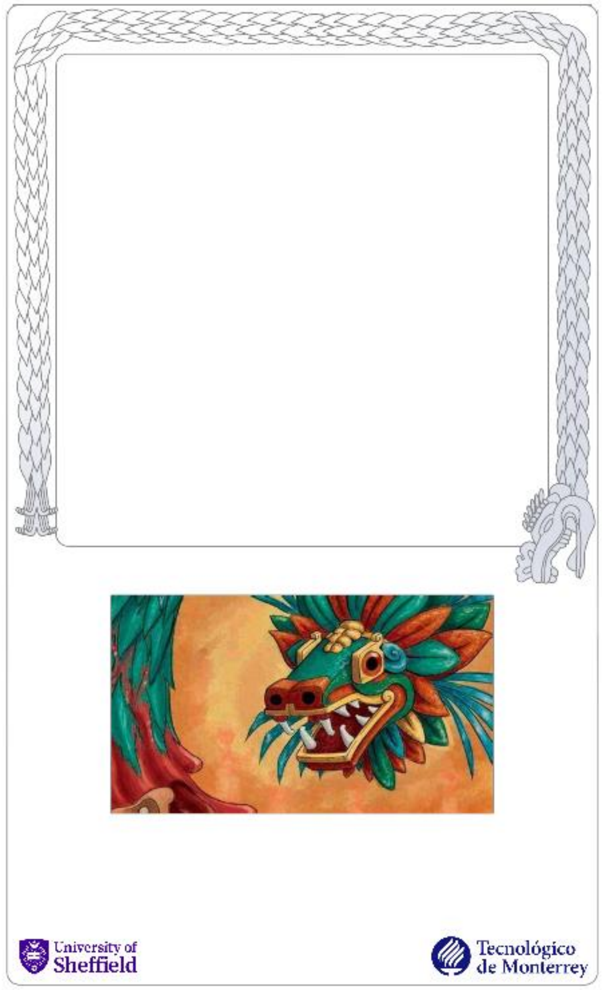


Figure 5. Base design created to place the cardboard model.

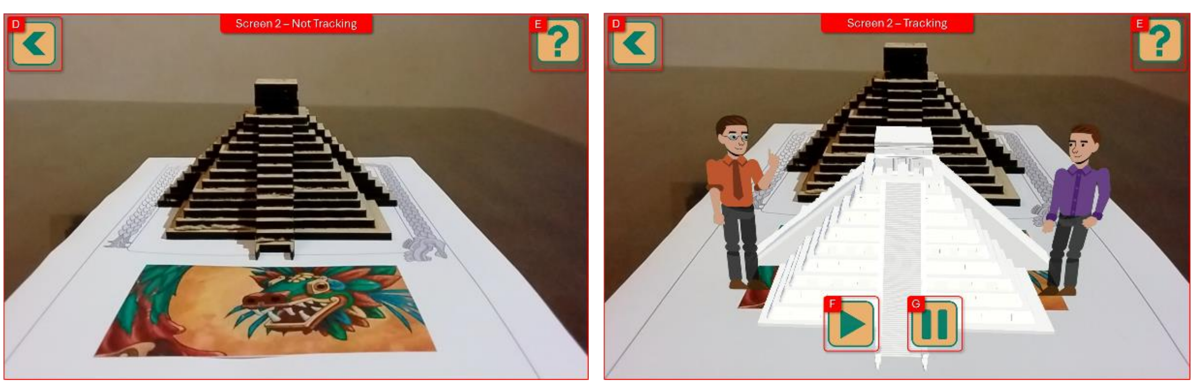
The AR experience is built into a mobile app called Kukulkan, Figure 6, that uses the Unity Engine. Additionally, it is developed in C# with support of the Vuforia Engine. This is later compiled as an APK and installed into Android tablets with built-in-cameras, since it is required for using AR.

Figure 6. Mobile app icon.

Figure 7 shows the main menu of the app, which corresponds to the first screen that the students face when the app on the tablet is launched. Button A is used to close the app while Button C presents information regarding the app's development. By pressing Button B, the app changes to a second screen which is used for the AR display.

Figure 7. Main menu of the app.

In the second screen, Figure 8 a), the camera is activated to start with the AR functionalities. The default configuration of this screen has a Button D, which is used to go back to the main menu. Once the tablet's camera is pointed towards the base design, the program recognizes the serpent image; thus, the character animation appears alongside a render of the 3D model slicing of the pyramid, Figure 8 b). Furthermore, when the program is tracking the serpent's image, two additional buttons are activated, Button F and Button G, which allow the students to stop and resume the animation, respectively. If the program loses track of the image, the animation, the pyramid render, and interface buttons disappear, returning the screen to its default state. Additionally, the app is configured to automatically pause the animation when the camera stops tracking the serpent's image, ensuring that learners do not miss any information if they momentarily shift their focus. Moreover, when the camera is repositioned on the base design and tracking resumes, the animation automatically continues from where it was paused.



a) Not tracking. **b) Tracking.**

Figure 8. AR experience.

Figure 9 shows the roadmap carried out by the research team to link AR and AI technology with the 3D model cardboard. Through this system, students are introduced to the historical and engineering characteristics of the Chichén Itzá pyramid, guided by a virtual assistant featuring an expert in the subject. Furthermore, Figure 10 shows the poster used in WUN webpage to promote the workshop.

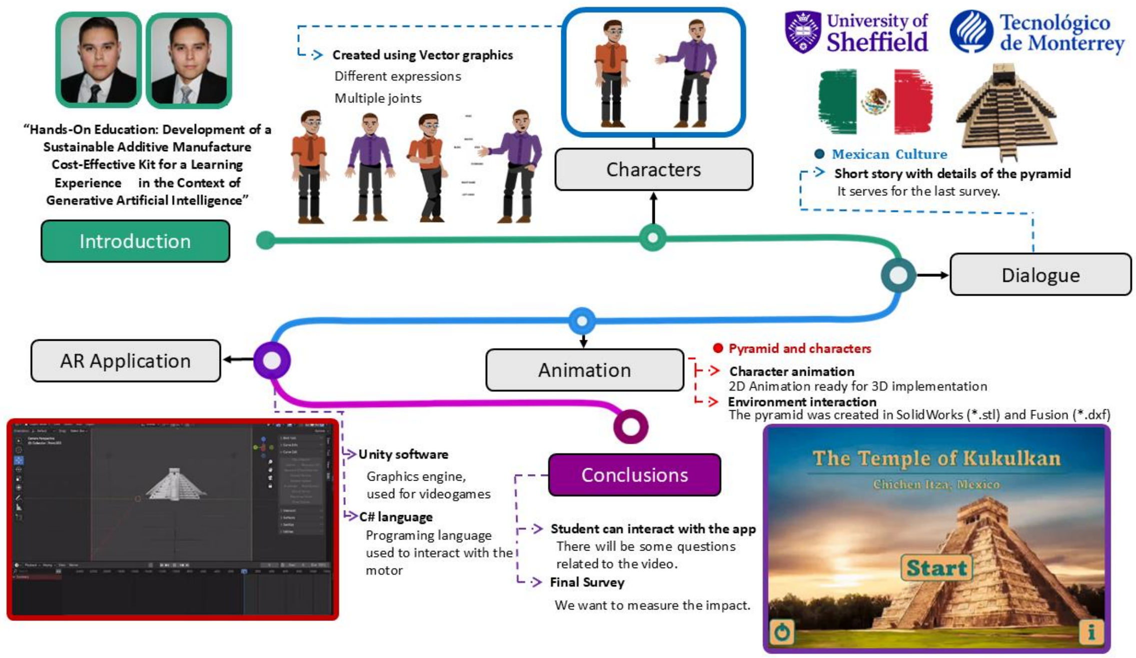


Figure 9. Roadmap to link AR and AI technology with the 3D model cardboard.

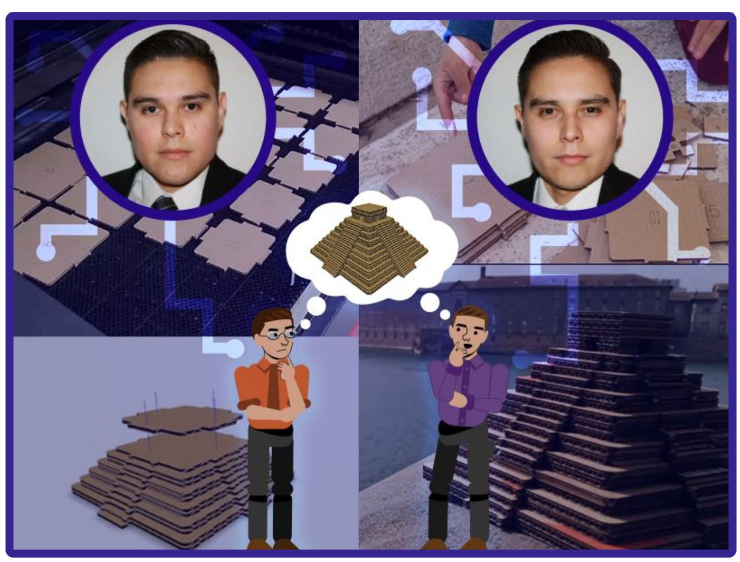


Figure 10. Workshop poster on WUN webpage.

Description of the Workshop Activity

Figure 11 shows the development of the workshop. The first two rows describe the activity carried out in an industry & steelmaking history museum while the third and fourth rows show the workshop implemented in a primary school in the Northeast of England. In both cases, the theme of the activity was the same, children experience AR and AI tools in "manufacturing" a model of the Chichén Itzá pyramid. The learning objectives of the workshop are the following:

- To design and build assembling models.
- To understand the importance of additive manufacture.
- To know the importance of AR and AI tools.
- To employ recycled materials (cardboard) for modelling.

Additionally, the workshop facilitators provided the following resources:

- Waste cardboard
- Adhesive tape
- PVA glue
- Paper for labels
- Tablet with scanner application

<u>Museum workshop (home education families)</u>

Primary school workshops

Figure 11. Workshop carried out with a-d museum assistants and e-f primary school students.

The workshop has four main stages: Introductory activity, 3D model development, Plenary activity and Extension activity:

Introductory activity. Before starting the main activity, everyday analogies of AM are used to connect children with the topic, e.g., how to assemble a sandwich. Workshop facilitators and/or teachers can remind children that many everyday materials are made up of recycled elements. Moreover, it is recommended to allow the children time to read through the information, discuss the AM processes of different materials with their group, and explore connections to AR and AI concepts. Afterwards, teachers must ask each group in turn to describe this process in their own words.

3D model development. The model building activity is explained, and resources are provided to each group. Using recycled and recyclable packaging materials reinforces responsible resources use. Working in groups and in their own time, children are encouraged to assemble their models while facilitators remind them of the layer-by-layer logic. At this point, teachers and facilitators can approach children to discuss their model making and offer other examples where additive manufacturing processes have been used.

Once the models are built, learners proceed to interact with AR and generative AI tools, mainly to:

- Introduce the historical and cultural context of the activity.
- Explain the additive manufacturing process.
- Provide facilitators and teachers with opportunities to connect the activity with interdisciplinary learning of Mathematics, Geography, History, or other related subject area or topic.
- Teach students about the importance of sustainable practices.

Furthermore, during this stage of engagement, children could be prompted to put forward reasons for using cardboard instead of another recycled material such as: paper, plastic, steel, glass, aluminum, etc. At this point, children could find out or reinforce ideas about paper recycling, introducing further complexity by discussing how the quality of recycled materials can change after a number of cycles. Steel, glass, and aluminum could also represent materials for children while plastics are harder to recycle, often requiring sophisticated industrial processes.

Plenary activity. The children present the 3D Model and facilitators encourage a discussion about the AM process [27] involving:

- The core concepts and evolving technologies of different AM processes.
- How they can create the design of an object suitable for AM processes and use commercial software to digitize the free-form geometry.
- The capabilities, procedures, typical applications, the relative advantages, and limitations of AM processes.

We also recommend that facilitators and teachers:

- Encourage children to recycle the assembled models once they are no longer needed or provide guidance on how to upcycle the materials for other projects. This ensures a more circular approach to resource usage.
- Consider providing digital versions of the 3D models and instructional materials, as explained in Figures 4-10.

Extension activity. Children could be motivated to investigate other similar manufacturing processes and how common these are in other countries. Finally, teachers and workshop facilitators could instigate discussions by asking:

1) Is it possible to use another way to assemble our models?
2) What could be the advantages or disadvantages of using AR and AI tools?

Costs

Considering both implementations, the industry & steelmaking museum and the primary school, Table 1 presents the costs for the 3D models developed during the workshop. Resources such as cardboard, glues and tape cost £ 200, here, 14 tablets with scanner application to use AR and AI are not taking into account because they were borrowed by Tecnologico de Monterrey. To prepare and pack 100 pc laser cut project sheets cost £ 1,602; although this item is the most expensive, this material is suitable for 90 school-age students. The payment for the website domain rights of AI digital platform is £ 30, this is used for the tutors to generate academic material related with Mexican Culture and develop the tutor cartoons. Additionally, the students use it to obtain more information about Chichén Itzá pyramid. On the other hand, administration costs for recognition visit to evaluate workshop space and manage booking is £ 150 while staff cost for specialist in implementation who develop and manage workshop delivery and evaluation is £ 729. Even though the amount of material used was reduced, students were able to build their own 3D model and compare them with the pyramids of their peers. This enhances STEM education, Figure 12.

Table 1. Workshop production cost considering 90 students.

Item	Price (GBP)
Resources (cardboard, glues and tape)	£ 200
100 pc laser cut project sheets	£ 1,602
AI digital platform website domain	£ 30
Administration	£ 150
Staff	£ 729

Figure 12. Workshop enhancing STEM education.

Conclusion

The article work, as part of the ongoing Research Development Fund 2023, presents an approach to teaching STEM through a cost-effective AM kit. Approximately 90 primary school-age students took part in workshops implemented in a museum and a primary school located in the North of England, integrating AR and AI were used. The 3D model chosen was the Chichén Itzá pyramid, selected not only to further Mexican Culture but also to teach science and engineering. Additionally, children interacted with animated university educators and experts on AM enhancing the interactive learning experience. This multidisciplinary and engaging workshop was designed using recycled materials, also integrating sustainability-related concepts and offering alternatives to mainstream STEM learning. Beyond material costs, we recognize that expertise in AM, AR, and AI is essential for designing the activity. This highlights the importance of transdisciplinary and interdisciplinary collaboration between educators and STEM ambassadors to replicate and expand initiatives like this workshop, which prioritize quality education. Furthermore, these collaborations, along with hands-on learning designs that offer multiple points of access, can enhance and promote inclusive and equitable quality education by ensuring broader accessibility and engagement to topics that are usually challenging for students.

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